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USER DATA DISSEMINATION CONCEPTS FOR EARTH RESOURCES

FINAL REPORT

Contract NAS2-8964

Prepared for:

NASA, AMES RESEARCH CENTER

SYSTEMS CONTROL, INC.
1801 Page Mill Road
Palo Alto, California 94304

Aeronutronic Ford
Aeronutronic Ford Corporation
Western Development Laboratories Division
3939 Fabian Way
Palo Alto, California 94303

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USER DATA DISSEMINATION CONCEPTS FOR EARTH RESOURCES

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R. DAVIES
M. SCOTT
C. MITCHELL
A. TORBETT

Contract No. NAS 2-8964

NASA TECHNICAL MONITOR
Edgar M. Van Vleck

Prepared for
NASA AMES RESEARCH CENTER
Moffett Field, California 94035

SYSTEMS CONTROL, INC.

Aeronutronic
Aeronutronic Ford Corporation
Western Development Laboratories Division
3939 Fabian Way
Palo Alto, California 94303

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GLOSSARY

NOMENCLATURE

ERS	-	Earth Resource Satellite
RAW DATA	-	Unprocessed Data
ET	-	Earth Terminal
SEOS	-	Synchronous Earth Orbit Satellite
LERS	-	Low-orbit Earth Resources Satellite
UOT	-	User-Owned Earth Terminal

SECTION 1.0

SUMMARY

This study was directed toward the evaluation of domestic data dissemination networks for earth-resources data in the 1985-1995 time frame. To accomplish this task, the following topics were addressed;

1) earth-resources data sources and expected data volumes,
2) future user demand in terms of data volume and timeliness,
3) space-to-earth and earth point-to-point transmission link requirements and implementation,
4) preprocessing requirements and implementation,
5) network costs, and
6) technological development to support this implementation

This study was parametric in that the data input (supply) was varied by a factor of about fifteen while the user request (demand) was varied by a factor of about nineteen. Correspondingly, the time from observation to delivery to the user was varied. This parametric evaluation was performed by a computer simulation that was based on network alternatives and resulted in preliminary transmission and preprocessing requirements.

The earth-resource data sources considered were: shuttle sorties, synchronous satellites (e.g., SEOS), aircraft, and satellites in polar orbits. As the average daily data volume from polar orbiters was found to exceed that from the other sources by nearly an order of magnitude, only polar orbiters were finally included in the data input model.

User requirements were assessed from careful reviews of prior earth resources user requirement studies and from extensive interviews within the current LANDSAT data user community. A lack of consensus among those interviewed, particularly on resolution and timeliness needs, led to the parametric user data demand model mentioned above in which important variables (including resolution and timeliness) may be modified. Timeliness requirements throughout the model were selected specifically with a view toward determining network capacity and structure for fast (less than nine-day) user-request response time. This ruled out the distribution of user data by mail or special courier.

Evaluation of transmission requirements resulted in the definition of link capacities and the comparison of alternate services to satisfy these requirements. Space-to-earth transmission included consideration of direct and relay links. Landline and satellite relay were considered for trunking and user dissemination.

The network simulation indicated required preprocessing speeds for the functionally identical network configurations. Though functionally identical,

the network configurations differ in the use of regional vs central raw data reception and regional vs central preprocessing and distribution. For a given configuration, the location(s) of these reception, preprocessing, and distribution facilities were selected from among Fairbanks, AK, White Sands, NM, Goldstone, CA, Sioux Falls, SD, and Greenbelt,MD. One configuration resembled the current LANDSAT network in that raw-data reception (or polar-orbiter readout) stations were located at Fairbanks, Goldstone, and Greenbelt, a central preprocessor was located at Greenbelt, and a central distributor was located at Sioux Falls. Another configuration postulated the use of NASA's Tracking and Data Relay Satellite (TDRS) so that all data was received at the White Sands TDRS terminal.

Given the transmission and preprocessing alternatives, costs were developed to compare these alternatives. The results of cost comparisons among the economically feasible electronic transmission alternatives showed satellite transmission (either a leased transponder or an add-on, user-owned transponder) with user-owned earth terminals to be the minimum-cost alternative.

The main criterion in the network comparisons was network cost for equivalent network performance. Network performance was based on the maximum data load (e.g., clear-weather operation, peak seasonal demand) and evaluated according to the number of user requests that were unsatisfied (i.e., not delivered to the user within the user-specified timeliness requirement) and the average age (from reception at the polar-orbiter readout stations to delivery to the user) of delivered data. Network performance was determined with the help of a discrete-event computer simulation program. This program modeled the complete network from source data volume through user data distribution and incorporated the parametric user demand model.

Network cost included the cost of raw-data readout terminals, data trunking, data preprocessing (that is, record and playback, reformatting, address insertion, channel redundancy removal, quick-look data extraction, cloud-cover extraction, radiometric and geometric correction, archiving, and data routing), and user data distribution. The cost of the polar orbiters and of the TDRS were not included. All costs were expressed as an equivalent annual cost based on a uniform equipment lifetime of 7 years and an 8% annual interest rate. In all networks, operation, administration, and maintenance costs combined comprised approximately 35% of the total equivalent annual network cost.

The total annual cost of networks for lower-48-state coverage, not including the user-owned terminals, ranged from $2.3M to $4.8M. Networks covering the lower-48 states plus Alaska ranged in cost from $2.9M/year when use of the TDRS was assumed to $4.4M/year for the network similar to the current LANDSAT network. In both coverage cases, the lowest cost network used central data reception, preprocessing, and distribution to the extent possible. This result is independent of likely uncertainties in the cost of preprocessing equipment and operating personnel.

The least-cost network configuration for coverage of both the lower-48 states and Alaska with the exception of the network in which the use of TDRS is assumed, receives polar orbiter data at Fairbanks and Sioux Falls. The Fairbanks data is then trunked to Sioux Falls for preprocessing together with the Sioux Falls data. A preprocessor throughput rate of 6 scenes/hour (10 min/scene), where a scene includes all the spectral bands, is sufficient to satisfy all user requests. The preprocessed data is then distributed from Sioux Falls via a network-owned domestic satellite earth terminal and a 6-Mbps satellite broadcast link. The associated average age of the delivered data is 9.9 hours. The total annual cost of this network is approximately $3.0M, only about $160K/year more than the TDRS-related network.

The single-unit installed cost of a user-owned terminal was calculated to be $109K for a G/T of 30 dB/^{o}K at 12 GHz. (Operation with a satellite EIRP of 40 dBW per 40-MHz transponder is assumed.) Or, the equivalent annual cost of the terminal, including maintenance, would be $31K. Given cost reductions in key earth-terminal components, these costs could be reduced to $58K and $21K, respectively, where half of the annual cost would then be allocated for maintenance. Assuming a 100-user network, an accompanying volume discount for the per-unit user-owned terminal cost, and equal sharing among users of the total cost of the network just described, the annual cost per user would be $51K. Assuming a user requests 500 scenes a year, the cost to him per scene would be about $100. Actual user cost per scene could vary significantly from this figure depending upon the degree to which the earth-resources program is subsidized by the government, the number of users sharing the costs, and the number of scenes required. Furthermore, user processing (classification, analysis, display) costs must be added to obtain the total cost.

Technology considerations indicated that 30m/7-band data could be disseminated, with current technology, to all users within 24 hours after observation. On the other hand, 10m/12-band data would require significant development, primarily in recording and processing technology.

The level of technology required is, in general, a function of either the transmission rate or the preprocessing time required per pixel to keep up with the data flow. At a raw data rate of 120 Mbps or less, the 14-GHz band will suffice, and present-day digital-component technology can be used. At higher rates, the ERS data transmission links must move to higher frequencies where technology is less developed. This is especially true at 40 GHz.

Existing technology is adequate to record the 30m/7-band data at 102 Mpbs. Furthermore, current development projects such as the RCA High-Density Multitrack recorder will extend the recording capability to 240 Mbps. At higher rates, research is required. The most promising technique appears to be optical recording.

Required developments in preprocessing technology include software development of automatic ground-control-point (GCP) matching necessary to perform accurate geometric correction. More accurate modeling of 3-axis satellite attitude variations (caused by solar pressure, for example) is necessary to improve geometric correction accuracy. In addition, the development of distributed processing techniques is necessary to achieve higher throughput rates. Alternatively, improved satellite jitter performance may reduce the number of GCP's required per scene during correction.

Issues that remain and to which the methodology developed during this study could be applied directly include the following:

- the effect of cloud cover on user demand and network sizing
- the preferred network structure(s) for expanded coverage (Hawaii, international)
- the effect of expanded mission responsibility (e.g., oceanic, meteorological) on network structure and sizing
- definition and economic evaluation of area center capability (user-unique processing, archiving, user interaction, etc.)
- design optimization (e.g., function of timeliness)

SECTION 2.0

INTRODUCTION

The launch of the Earth-Resources Technology Satellite (ERTS) in July, 1972, marked the beginning of a new era of data collection, processing, and dissemination for a broad spectrum of users involving numerous institutions (public and private), missions, and technical disciplines. Indeed, data requirements, as now imposed, are diverse in quantity, accuracy and application.

The technical capability of earth-resources data sensors (both satellite and airborne) will increase significantly over the next 10 years. As these capabilities increase, user requirements should also increase in complexity and accuracy demands. New methods for transferring and processing the data should, therefore, be required to meet this future demand.

The existing domestic data processing and dissemination system for earth-resources data consists of three earth terminals located at GSFC (Greenbelt, Maryland), Fairbanks, Alaska, and Goldstone, California. Preprocessing is performed at GSFC, and the data is disseminated to the user via a distribution facility at Sioux Falls, South Dakota. The collection, preprocessing, and dissemination functions include numerous steps which result in a system time response in the order of 30 days. Factors which contribute to this response time include the following: (a) administrative handling of data requests, (b) mailing of raw data tapes from Fairbanks and Goldstone to GSFC, (c) manual checking and editing of preprocessed data prior to release to Sioux Falls, (d) mailing of data to Sioux Falls, (e) time required to handle and process user requests at Sioux Falls, (f) time to mail data to the user.

Steps are underway to reduce this response time. A new, high-speed processor is being developed by IBM for GSFC which will preprocess a scene (90m resolution/4-spectral-band LANDSAT-A image) in only 2 minutes. Plans are underway to lease a domestic satellite transponder to provide a 20-Mbps data transmission link between Goldstone and GSFC, and between GSFC and Sioux Falls. With these improvements, the network response time is expected to be reduced from 30 days to 2 or 4 days plus the time required to transfer the data from Sioux Falls to the user [1].

It is clear that if substantially faster response times to the user are required, data transmission links from the preprocessor directly to the user must be implemented. Furthermore, administrative delays must be eliminated by scheduling user requests in advance. Finally, geometric and radiometeric corrections, data editing, and quality control techniques must be improved and maintained without adding significant delay to the system.

On July 14, 1975, NASA/Ames Research Center awarded a contract to Aeronutronic Ford to study user data dissemination concepts for domestic earth-resources data. The purpose of this study is to predict the requirements for earth-resources data in the 1985-1995 time frame, to evaluate competing networks for data processing and dissemination, and to indicate technological development required to support implementation of this data flow. Figure 2-1 shows the plan followed in conducting this study. The study was divided into three basic tasks:

1. Predict user requirements and construct a user model for the 1985-1995 time frame.
2. Predict capability and cost of data processing and communication techniques.
3. Configure, analyze, and evaluate a number of networks for processing and disseminating the earth-resources data to the user.

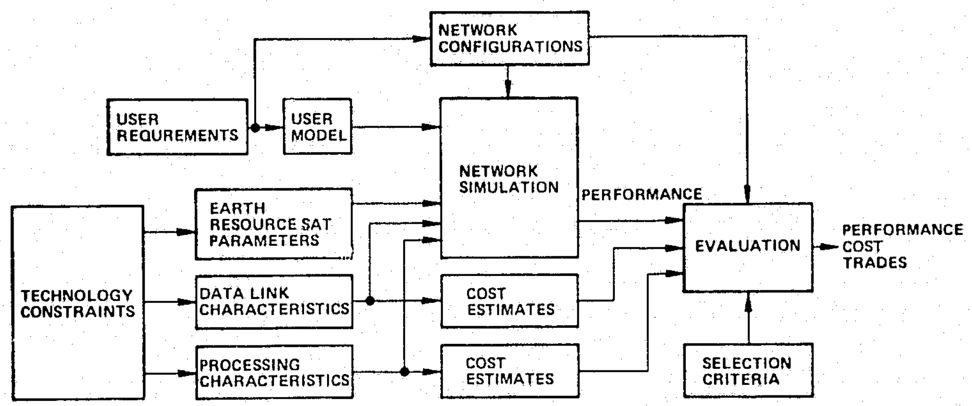


Figure 2-1. Study Plan

To assist in the analysis and evaluation process, the data dissemination network was simulated on a computer, using a discrete event simulation language (GESIM). The principle criteria used in evaluating the networks were the time required to process and transfer the data to the user and the cost to implement and operate the network.

As seen in Table 2-1, the rates and quantities of data to be generated by future ERS satellites are much larger than those currently generated by LANDSAT A. Two levels of future satellite sensor capability were assumed, one with a 30-meter resolution, 7-spectral-band scanner, and the other with a 10-meter resolution, 12-spectral-band scanner.

The functions of the data processing system considered in this study are those associated with preprocessing only. These include reformatting, quick-look data extraction, radiometric and geometric correction, among other functions. Data interpretation, classification, and other user-peculiar processing were outside the scope of this study.

Table 2-1

Parameters of Polar Orbiters

(Multispectral Scanner Only)

	LANDSAT A	LANDSAT D (TENTATIVE)	FUTURE LANDSAT
Resolution (m)	90	30	10
Number Spectral Bands	4	7	12
Raw Data Rate* (Mbps)	15	102.4	1579.2
Number Bits per Pixel	6	8	8
Number Bits per 8-min Pass**	7.2×10^{9}	4.92×10^{10}	7.58×10^{11}

Finally, key technology development requirements were identified and described. These requirements lie principally in the area of preprocessing; particularly, high throughput speeds in the order of 1 microsecond per pixel. Data transmission technology appears basically adequate to support earth-resource network requirements.

A data dissemination network can be considered in terms of its primary functions. These are: data transmission from space to ground, reception and storage at regional terminals, trunking from regional terminals to a central facility, quick-look data extraction and dissemination to users, preprocessing, archiving and, finally, dissemination of preprocessed data to the user.

To support these functions, a network topology can take many forms. For example, the space-to-earth link may be implemented directly, as now, or through a synchronous-satellite relay. For domestic data, the number of regional terminals can vary from none (satellite relay) to four (required coverage for 40-GHz carrier). The regional location and timeliness requirements principally determine the trunking capacities. Quick-look extraction, preprocessing, and dissemination may be performed regionally or centrally. As stated previously, one of the purposes of this study was to evaluate these competing alternatives.

A previous study was performed by National Scientific Laboratories, Inc., [2] in 1974 for NASA/GSFC. Four networks were considered in this study:

1. Raw data collected at Goldstone, Greenbelt, and Fairbanks transferred to and preprocessed at Greenbelt, and transferred to Sioux Falls.
2. Raw data collected at Fairbanks and Sioux Falls and preprocessed at Sioux Falls.
3. Raw data collected via TDRS at White Sands, transferred to and preprocessed at Greenbelt, and transferred to Sioux Falls.
4. Same as network (3), except a second preprocessing facility at Sioux Falls was added for operational data processing. The Greenbelt processing facility was retained for experimental data.

Though considering only the trunking requirements by excluding user data dissemination and based on a 15-Mbps raw-data rate transferred to Sioux Falls within 4 hours after observation, this NSL study concluded that alternative 2 was least expensive. This conclusion is similar to conclusions appearing in Section 11 of this report.

Certain assumptions were made at the beginning of the study. These are listed in Table 2-2. While these assumptions may affect the choice of an optimum system, they will not affect the basic methodology developed to attack the problem. For example, in a future study, areas other than continental USA could be added to the network simulation. The earth terminal locations could be changed. Data processing (including data compression) in the satellite could be simulated.

Table 2-2

Basic Assumptions

- 1985-1995 TIME FRAME
- CONTINENTAL U.S.A. (INCLUDING ALASKA) COVERAGE ONLY
- TWO SATELLITE ORBITS
  - LOW ORBIT (700-920 km), CIRCULAR, SUN-SYNCHRONOUS
  - SYNCHRONOUS, GEOSTATIONARY
- FIVE POSSIBLE EARTH TERMINALS FOR ERS DATA RECEPTION
  - GREENBELT, MD
  - SIOUX FALLS, SD
  - GOLDSTONE, CA
  - FAIRBANKS, AK
  - WHITE SANDS, NM
- PREPROCESSING PRIOR TO DISSEMINATION
- DIGITAL DATA TRANSMISSION
  - ONE WORD PER PIXEL
  - 8 BITS PER WORD
- COMMON FORMAT AND COORDINATE SYSTEM TO USER
- SYSTEM SIZED FOR MAXIMUM INPUT DATA RATE
  - CLEAR WEATHER OPERATION
  - PEAK SEASONAL DEMAND
- IR SENSOR RESOLUTION SAME AS VISUAL
- RADIO FREQUENCY ALLOCATIONS AND FLUX DENSITIES CONFORM TO EXISTING ITU/CCIR AGREEMENTS
- 16-HOUR SHIFT, 7-DAY WEEK

The criteria used for network evaluation were; network performance, cost, and technology risk. The measure used for network performance was the percentage of users that received the data requested within the time required (i.e., acceptable network response time). Cost and technology risk were determined for each network.

This final report is organized as follows: Section 3 describes the parameters of earth-resources data which may be available to the user community by 1985. Section 4 summarizes the results of the work performed to determine a basis for predicting a user model valid for the 1985-1995 time frame. This user model is described in Section 5. In Section 6, network alternatives are described.

Section 7 presents performance-cost trades for data transmission systems, and Section 9 presents performance-cost trades for data processing systems. These results are referred to in Sections 8 and 11, which describe and evaluate the various data dissemination networks considered. Section 9 describes a preliminary selection process based largely on cost considerations. From this process, several configurations were selected for further investigation by computer simulation, described in Section 10. These results are presented in Section 11. Finally, future anticipated technology requirements are outlined in Section 12, and the study conclusions and recommendations for future study are presented in Section 13.

SECTION 3.0
EARTH RESOURCES PLATFORM PARAMETERS - DATA SUPPLY

3.1 Introduction.

An effective user model must project both the supply and demand of and for remotely sensed data. As the model is parametric, so must be the data supply. The supply side will be constrained by the availability of platforms and sensors and the data flow will be structured by the orbital parameters, number of satellites and their relative timing. Thus, the purpose of this section is to develop reasonable bounds on the parameters that affect the data input to the model.

The types of platforms investigated were:

a) polar orbiter
b) synchronous earth-resources satellite
c) shuttle scanner experiments
d) aircraft imagery required to support satellite data

For each of the above platforms, a variation in data output was assumed. Typically, the lower bound of data load was based on current planning and the upper bound was established by a significant extrapolation of current planning. The structure of these estimates is discussed in the following sections.

3.2 Polar Orbiters.

Assuming a standard swath width, the principal parameters that influence the data rate from each polar orbiting satellite are spatial resolution and number of spectral bands. The satellite orbital parameters have marginal impact on data rate but do affect the coverage at regional terminals and trunking requirements to a central preprocessor.

3.2.1 Spectral Bands: The initial effort in estimating the number of spectral bands (and spatial resolution) was to review existing recommendations. The results of six sets of spectral band recommendations for different disciplines appear in Appendix A. The studies or reports referred to are:

1. General Electric, TERSSE Study - November, 1974
2. Operations Research, Data Origination and Flow for Advanced Earth-Sensing Satellites in 1985 and Beyond - June 1975

3. NASA, Advanced Scanners and Imaging Systems for Earth Observations - December 1972
4. ERIM, Multispectral Scanners Data Applications - December 1974
5. NASA, Earth Observation Satellite Payload Discussion Group
6. NASA, Synchronous Earth Observation Satellite

A review of Appendix A indicates an obvious lack of consensus within a given discipline and a lack of commonality between disciplines. Thus, a precise prediction of the number of simultaneous bands in use by 1985 is not likely. Also implied are cost trade-off decisions between discipline-dedicated satellites and single-satellite service with time-shared bands. In the latter event, the number of simultaneous bands will be limited by technology; i.e., the space limitation on filter wheels, multiple apertures, and/or fiber optics bundles. In considering shuttle era earth-resources satellites, the larger payloads imply the possibility of larger sensor apertures and thus narrower spectral bands with equivalent signal-to-noise performance. Thus, future sensors may be capable of inserting a wide range of bands of which some number would be selected by command on any given pass. Such capability would imply user interaction through an operational control center.

Recommendations for the LANDSAT-D thematic mapper were also considered. Current recommendations resulting from the LANDSAT-D Thematic Mapper Technical Working Group (June 1975) are for seven bands [1]. These are:

0.45 - 0.54	0.80 - 0.91
0.52 - 0.60	1.55 - 1.75
0.63 - 0.69	10.4 - 12.5
0.74 - 0.80	

This recommendation was based primarily on the objective of detection and classification of vegetation.

An important factor to be considered in projecting spectral bands is the relationship between the number of spectral bands and classification accuracy. An interesting empirical study on this subject was reported by ERIM in the "MSS Data Applications Evaluation Study" (Dec. 1974). Using actual data derived from aircraft overflights, ERIM analyzed classification accuracy by discipline as a function of number of bands, spatial resolution, and noise equivalent-radiance difference. Among conclusions of this study were:

1) Vegetation classification can be accomplished as well with four or five optimized bands as with twelve.

2) Little improvement in classification of land use (Anderson Levels I through III) was achieved by increasing the number of bands from four to twelve.

3) Increasing the number of bands for rock and soil classification did improve the classification accuracy.

Figures 3-1 and 3-2, taken from the ERIM Study, depict the classification accuracy as a function of number of bands for agriculture and geology, respectively. It should be noted that the geology application has a minimum likelihood of rapid data transmission requirements so that, while a demand for increased bands by this discipline may influence the supply or band availability, this demand will not necessarily appear in the user model. That is, the quantity of data, as determined by the number of bands, will likely exceed the quantity of data demanded on direct communication links.

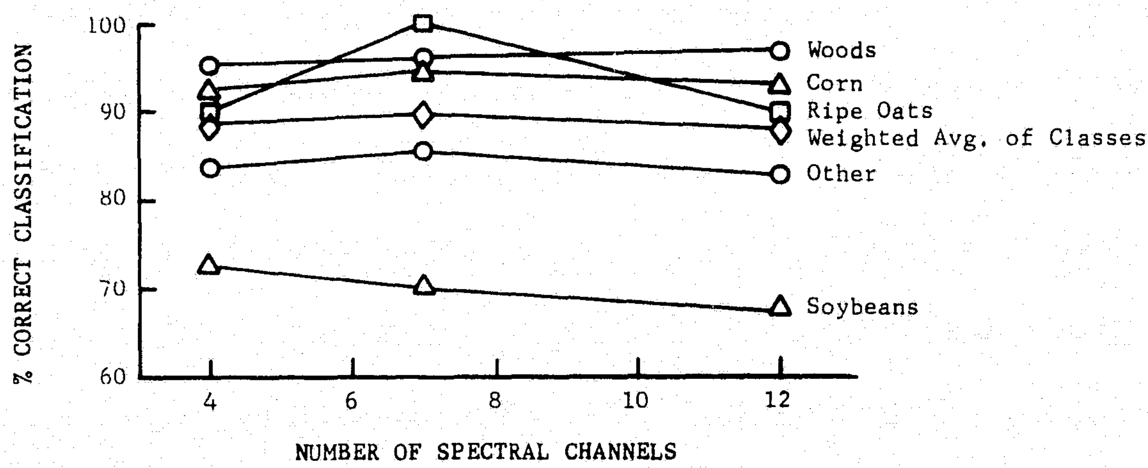


Figure 3-1. Classification Accuracy

In summary, the minimum number of bands assumed for this study was seven (equivalent to current LANDSAT-D planning) and the maximum was twelve.

3.2.2 Spatial Resolution: The resolution requirements specified by the various studies previously cited and by earth-resources data users vary considerably for any given application. There is, however, a prevailing attitude that increased resolution to 30m or 10m will increase the utility of remotely sensed data. Numerous potential applications were so stated; examples: 1) seepage and ground water detection [2], 2) county level

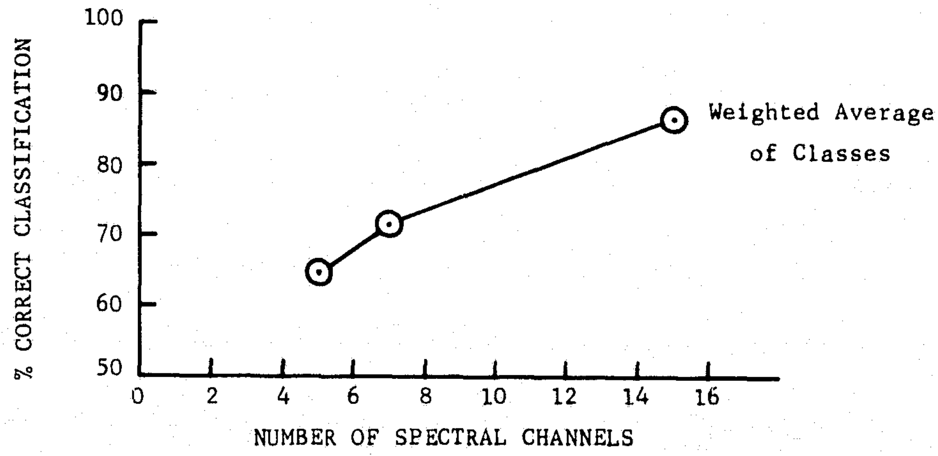


Figure 3-2. Classification Accuracy

mapping at 1:100,000 scales [3], 3) sediment mapping[4], 4) land management surveys[5], 5) aquatic plant mapping [6], and 6) oil spill monitoring to predict drift patterns[7].

However, countervailing factors also exist. To begin with, increased resolution implies increased transmission and processing costs. Furthermore, Department of Defense regulations may prevent NASA from operating sensors with spatial resolution less than 30m. This was apparently one reason for delaying the High-Resolution Pointable Imager (10 meter) development. In addition, as will be indicated in subsequent sections of this report, implementation of 10m resolution will require significant technological development. Finally, there is some empirical evidence that resolution less than 30m to 40m does not improve classification accuracies in the disciplines of agriculture and land use [8].

For the purpose of supporting the user model, the spatial-resolution range assumed for polar orbiters is 30m (current LANDSAT D recommendation) to 10m.

3.2.3 Satellite Parameters: Total network data loading and data handling cost is proportional to the number of polar orbiters in simultaneous operation. One frequently cited shortcoming of ERTS/LANDSAT data is the poor coverage cycle. This 18-day cycle limits the potential of satellite data for several applications. For example, agriculture applications are hampered by the combination of repeat cycle and cloudiness. For the single ERTS, only one total cloud-free coverage of the corn belt area was available over the entire 1975 growing season[9]. Satellite data appears highly useful as a support for snow melt and river flow models. A one- to two-day timeliness (from observation to user data delivery) is required for this application. In the Pacific Northwest, approximately

15 LANDSAT scenes are required for this application. During the period of interest (March to June), only about 4 or 5 cloud-free scenes occurred. This type of application implies a need for multiple, simultaneous polar orbiters and, thus, a cost/benefit trade. For the purposes of data input modeling, one and two satellites were assumed.

Given any number of satellites, the orbital parameters will influence the downlink data rate and the timing of data dumps at any regional terminal. In order to investigate these effects, two orbits were selected representing extremes in likely sun synchronous orbits. These were the current ERTS/LANDSAT orbit and the recommended LANDSAT-D orbit. The characteristics of these orbits are:

	ERTS/LANDSAT	LANDSAT-D
Altitude (km)	920	702.4
Ground track velocity (km/sec)	6.46	6.76

The real-time bulk data rate at the satellite can be derived from the following expression:

$$R_b = \frac{b\ n\ S_w\ N\ V_g\ m}{e\ r_g^2}$$

Where: R_b = real-time bulk data rate, bits/sec

b = overhead factor

n = number of spectral bands

m = samples per IFOV

S_w = swathwidth, meters

N = number of bits per pixel

e = scanner efficiency, %

r_g = spatial resolution, meters

V_g = ground track velocity, meters per second

Variation in most of these parameters can be eliminated by assumptions associated with standard design practices and the orbit. The overhead factor, b, will typically change inversely to data rate being as high as 20% at 10 Mbps or lower. A constant 10% overhead was assumed. Swathwidth, S_w, is currently standardized at 185.2 km, a value presumed to be maintained. Some consideration has been given to a dual scanner configuration for LANDSAT D. This configuration would have a 370-km swathwidth. However, the final recommendation of the technical working group was for a single scanner, 185.2-km swathwidth[10]. Scanner efficiency is dependent on scanner design, varying from 40% for single-

direction scanners to 85% for bi-directional scanners. A value of 80% was assumed. Eight bits per pixel and one sample per IFOV were also assumed. Data rate dependency on resolution and number of spectral bands then can be expressed for both orbits. These expressions are:

$$R_b = 1.377 \times 10^{10}\ n/r_g^{\,2} \qquad \text{(LANDSAT D)}$$

$$R_b = 1.316 \times 10^{10}\ n/r_g^{\,2} \qquad \text{(ERTS/LANDSAT)}$$

Given the assumptions on number of spectral bands and spatial resolution, the range in bulk data rate results immediately. This range is:

	LANDSAT D		ERTS/LANDSAT	
r_g(m)	30	10	30	10
n	7	12	7	12
R_b(Mbps)	107.1	1652.4	102.3	1579.2

It should be noted that the foregoing calculations assume that the infrared spatial resolution will be equal to the visible spatial resolution. This is not the case and the data rate estimates, as derived, tend to overstate the actual data rate. On the other hand, one sample per IFOV understates the current practice of oversampling in the scan direction and, thus, understates actual data rates. As a final comment, the 10% overhead factor may be considered a low estimate, particularly for precision mirror position data. In this regard, it should be noted that the 80% scan efficiency allows 20% time for either overhead insertion (increasing overhead factor) or on-board stretching of the time base (reducing data rate).

Daily data loads can then be estimated using current ERTS orbits. The maximum daily data load for a single satellite (CONUS and Alaska) is for passage over swaths 11, 29, 47 (CONUS) and 65, 83 (Alaska). For continental-shelf coverage, total time over CONUS is 14.7 minutes and over Alaska 6.1 minutes or 20.8 minutes total. For 30m resolution in a 920-n.mi. altitude orbit, this results in 1.28×10^{11} bits. For 10m resolution in the same orbit, the maximum daily data load would be 1.97×10^{12} bits. The average time over CONUS and Alaska for a single satellite at 920-n.mi. altitude in the 18-day coverage cycle is 17.8 minutes which corresponds to 1.09×10^{11} and 1.68×10^{12} bits average daily data loads for 30m and 10m spatial resolution. Two satellites would double the above average loads to approximately 2×10^{11} and 3.4×10^{12} bits. These estimates ignore the effect of cloud cover which would tend to reduce the average daily loads.

3.3 Synchronous Earth Observation Satellite (SEOS).

The SEOS program is in the Phase-A study period; consequently, current projections of SEOS data impact in 1985-1995 will be speculative. The models presented in this section attempt to bound current design information.

Currently, SEOS planning involves a common telescope system with two instrument packages (meteorology and earth resources) that are time-shared. The projected earth resources instrumentation will contain from 8 to 13 bands with a visible resolution of 100m and an infrared resolution of 800m. The instrument field-of-view or sector size will be 100 km to a side with a scan rate of 1 scene/min. Current planning indicates a single reception center that performs radiometric and geometric corrections, reformatting then retransmitting in standard map format, possibly through SEOS, to users. Approximately 20 earth-resources applications have been identified with emphasis on vegetation and water disciplines and emergencies.

An estimate of the number of earth-resources scenes scanned per unit time (say one day) would be soft. First, the earth-resources instruments must share time with the meteorological instruments. However, at a scan rate of 1 scene per minute, 100m resolution, 10^6 pixels/scene, 50% duty cycle and 8 bits per pixel, the real-time data rate would be 2.66×10^5 bits/sec. per visible band. For 10 bands, this would give 2.66 Mbps plus overhead, or, for a 10% overhead, 2.92 Mbps. A maximum daily data load (for 12 hours direct earth-resources observation) would be about 1.27 and 10^{11} bits.

A more reasonable data load expectation would be based on potential data demand. This was investigated by estimating the data content of some natural disasters and the monitoring of coastal waters.

The April 1974 tornado superoutbreak was used as an example of a maximum short-term data demand for SEOS earth-resources data. Figure 3-3, taken from a map produced by Dr. Fujita of the University of Chicago [11], depicts the extent of this tornado outbreak. Bearing in mind that the SEOS would be assessing damage and thus covering areas in excess of actual sightings, the potential area coverage could be estimated as follows:

Entire state surveillance	
Indiana	36,291 sq. miles
Kentucky	40,395 sq. miles
One-half state surveillance	
Tennessee	21,122 sq. miles

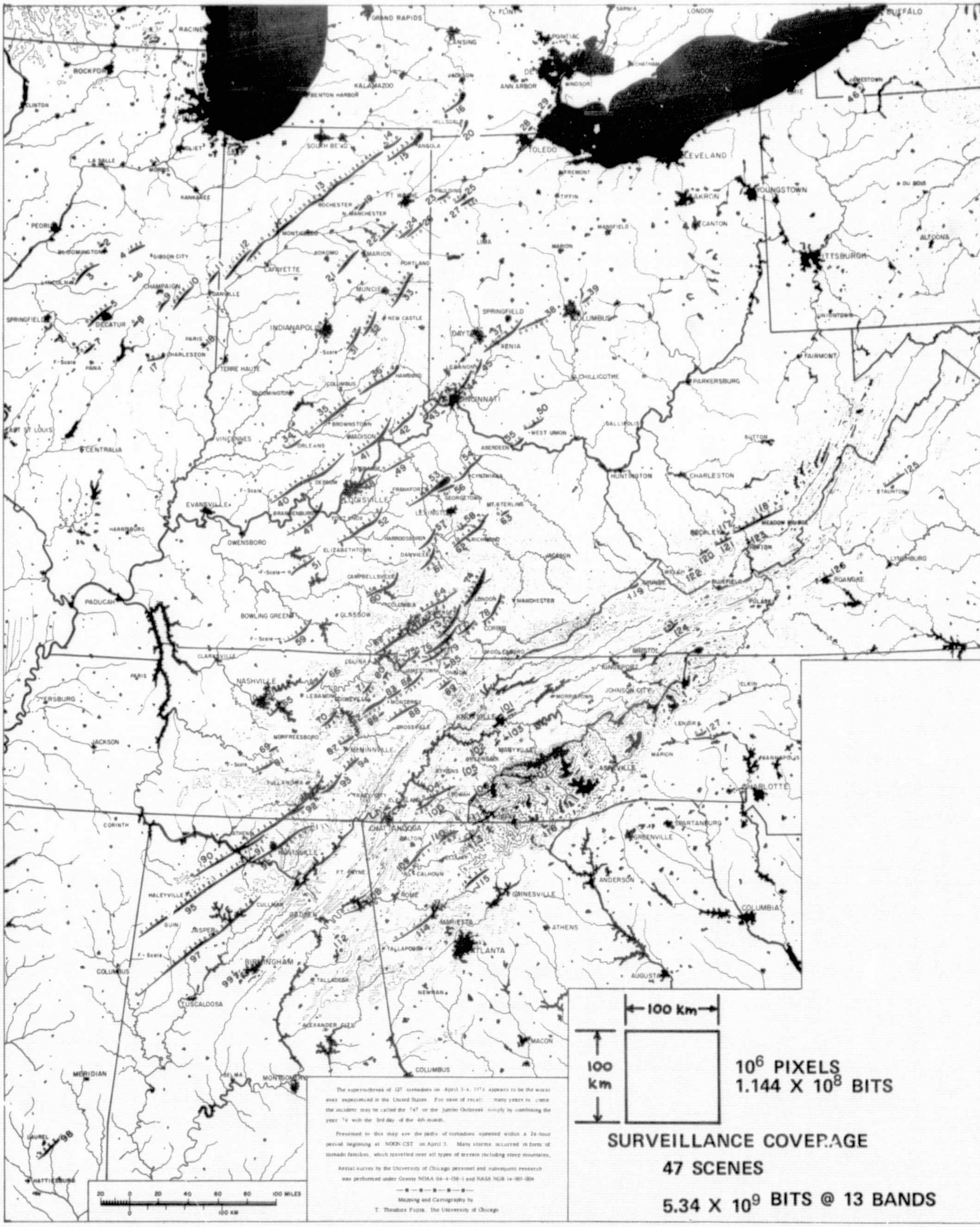


Figure 3-3. Example SEOS Demand Superoutbreak of Tornadoes of April 3-4, 1975

One-third state surveillance	
Alabama	17,203 sq. miles
Illinois	18,800 sq. miles
Ohio	19,740 sq. miles
Miscellaneous	
Virginia, West Virginia, Georgia	20,000 sq. miles
TOTAL	173,661 sq. miles

This area is equivalent to 4.67×10^{11} square meters or 4.67×10^{7} SEOS visible pixels. At 8 bits/pixel, 13 bands and 10% overhead, this is equivalent to above 5.34×10^{9} bits of data. If converted directly to SEOS scenes, this data would represent about 47 scenes.

By comparison, approximate areas involving other natural disasters and coastal waters are:

Event	Area (Sq. Meters)	Equivalent No. of SEOS Scenes	No. of Bits @ 13 bands 10% Overhead
Mississippi flood (1975)	2.43×10^{8}	1	2.78×10^{6}
Hurricane Camille (Miss. Gulf Coast)	4.76×10^{6}	1	5.45×10^{4}
Tornado Superoutbreak (April 1974)	4.67×10^{7}	47	5.34×10^{9}
Coastal Area (Main through Georgia)	-	25	2.86×10^{9}
Coastal Area (Florida through Texas)	-	35	4.0×10^{9}
Coastal Area (Calif. through Wash.)	-	23	2.63×10^{9}
Coastal Area (Alaska)	-	125	1.43×10^{10}

The foregoing information indicates that the maximum data load from a SEOS-type satellite could be approximated at 1.27×10^{11} bits and, with 50% time-sharing with the meteorology payload, 6.35×10^{10} bits. The demand for a large area natural disaster could be approximated at 5.5×10^{9} bits. Though not likely to be a requirement, the coastal waters, excluding Alaska, if mapped in a single day, would generate about 9.5×10^{9} bits.

Thus, the estimate of the average daily data load from SEOS ranges between 7×10^{9} and 7×10^{10} bits. The conclusion is that SEOS data loads would be an order of magnitude less than the data loads from two polar orbiters.

3.4 Earth-Resources Shuttle Sortie Mission.

The Earth Viewing Applications Laboratory (EVAL) is a sortie payload designed to contain general-purpose equipment that can be modified easily or adapted easily to accept new sensors in order to optimize a particular observation or to alternate between different kinds of measurement. The EVAL provides an unpressurized instrument environment on its open pallets and a pressurized space inside its optional Spacelab closed module. A variety of orbit inclinations will be available for mission durations from 7 to 30 days. The EVAL will supplement free-flyer operational earth-resources systems by providing for self-sufficient scientific measurements which require only a short period of observation. It will allow calibration of instruments already deployed on free-flying spacecraft, will carry out signature studies, and will test instrumentation or techniques as precursors to later free-flyers.

Multispectral sensor missions from the shuttle will tend toward research and development, thus, in general, negating the requirement (and cost) for rapid data dissemination. However, some research requires timely data delivery. Furthermore, the potentially higher resolution and varied spectral bands imply that an operational demand could develop. One implication of timely data delivery from the shuttle is real-time data transmission via the TDRSS.

Typical of the earth-resources experiments that may be flown on sortie missions is the Advance Technology Experiment number EO-3 being planned by Langley Research Center. This experiment is a multispectral scanner with the following parameters:

Number of simultaneously scanned lines:	50
Number of pixels per line:	1000
Number of bands:	8
Word size:	8 bits

The data acquisition rates are 22.8 Mbps without overhead and 23.3 Mbps with overhead. The data acquisition time for a 7-day mission is a total of 1.66 hours (100 minutes), comprised of 2 ten-minute passes for each of 5 days. The daily traffic for 5 days thus generated is 2.74×10^{10} bits or the equivalent of eightly-eight 1600-bits-per-inch computer-compatible tapes (CCT's). This data load, even if fully used on an operational network, is relatively minor compared to the daily polar orbiter data load (10^{11} bits/day).

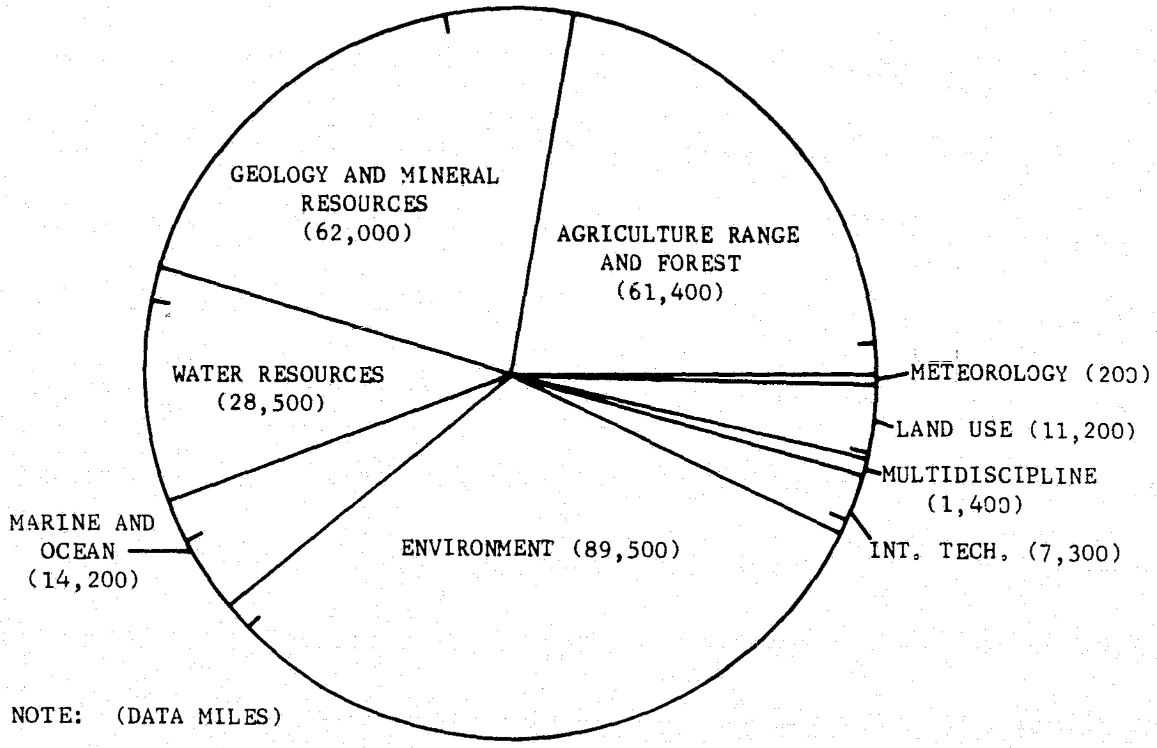
3.5 Aircraft.

Aircraft data loading on a rapid data dissemination network is difficult to predict. There are factors that both favor and de-emphasize the potential use of aircraft data on such a network.

To begin with, the aircraft program is research oriented with increasing emphasis on radio frequency sensors. A new mission out of NASA JSC now requires, at least, a two-week scheduling period[12] which would preclude much timely operational support. In addition, several agencies such as the Corps of Engineers and the Coast Guard use support aircraft directly on a district basis obviating the need for a data dissemination network. On the other hand, multi-stage sampling associated with timely data would require network dissemination.

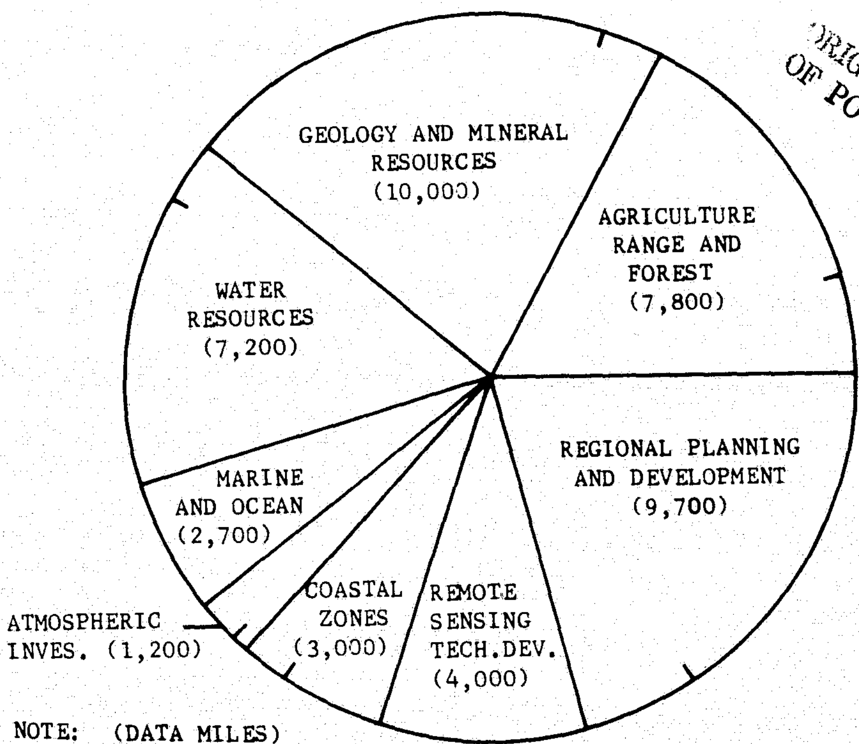
Two approaches were used to estimate potential aircraft data loads on a dissemination network. First, current NASA JSC aircraft activity was used to develop an estimate. During the period from July 1972 to February 1974, approximately 71%[13] of all NASA aircraft photographic activity was associated with JSC. The current yearly estimate of original feet of film generated by JSC aircraft is 35,457 feet. Thus, one estimate of total daily activity would be 50,000 feet divided by 260 working days or about 200 feet per average day. Only a fraction of this total would be time dependent; that is, require network dissemination.

Another approach was to take the two-year ERTS- and EREP-related aircraft activity, estimate the percentage of this data that is related to time-dependent disciplines, then derive an average daily footage as above. Figures 3-4 and 3-5, taken from the referenced Ferandin Report, indicate total data miles by discipline over a two-year period. Time-dependent satellite data will tend to be associated with the disciplines of agriculture, range and forest, water resources, environment and, to a lesser extent, coastal zones and marine and ocean. These categories constituted about 71% of the total ERTS-data miles and 49% of total EREP-data miles. Total photographic data products associated with ERTS-1 from three NASA centers and a contractual effort by ERIM is 655,000 feet and for Skylab/EREP 175,400 feet [14]. Thus, 465,000 and 85,946 feet of photographic products would be associated with the potentially time-dependent disciplines. This converts to an average daily footage of about 1057 feet over 520 working days. Again, only a fraction of this data is time dependent.



NOTE: (DATA MILES)

Figure 3-4. Aircraft Support By ERTS Discipline



NOTE: (DATA MILES)

Figure 3-5. SKYLAB/EREP Aircraft Support By EREP Discipline

The two foregoing daily estimates, 200 feet and 1057 feet, represent average daily products in disciplines that have time-dependent applications. Assuming 10% of this data is used on a dissemination network, an estimate of average digital data loads can be derived. This estimate was based on the following assumptions:

1) The photographic images are 9.5-inch square formats equivalent to 14 n.mi. to a side
2) Three-meter resolution
3) Eights bits per resolution element

One foot of film would, therefore, represent 14 by 17.64 n.mi. or about 8.47×10^8 sq. meters. At three-meters resolution and 8 bits per resolution element, each foot would represent approximately 7.5×10^8 bits. The upper bounds, previously estimated (20 feet and 106 feet), give potential average daily data loads of 1.5×10^{10} and 7.92×10^{10} bits. The central question relative to a data load projection is the relative role of aircraft-to-satellite data use.

Another approach to developing a daily estimate of potential data loading by aircraft is to estimate the coverage requirements for a natural disaster such as the 1975 Mississippi flood used for the SEOS calculations in Section 3-3. In this instance, 2.78×10^6 bits were estimated for 100m resolution. At a 3m resolution, this load increases to about 3×10^9 bits.

Another factor to consider is peak data loading. Figure 3-6 depicts a relative scale of aircraft activity with photographic data delivery history. This data indicates that the monthly-peak-to-average-activity ratio should not substantially exceed a factor of two. The previous estimates indicate a potential aircraft data load of the same order of magnitude as projected satellite data loads. Furthermore, EROS product sales shown in Table 4-1 indicate that aircraft product sales are roughly equivalent to LANDSAT product sales over a three-year period.

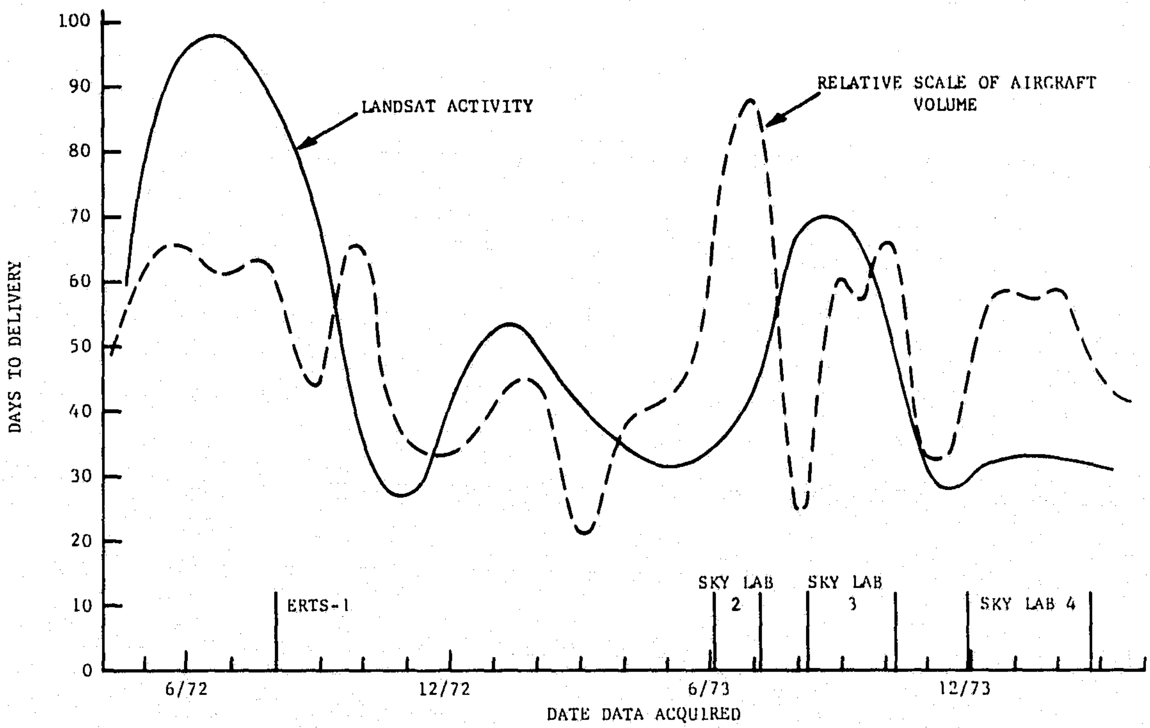


Figure 3-6. Photographic Data Delivery History

3.6 Conclusions.

Of the four platforms considered, polar orbiters represent the largest potential average data load on a data dissemination network for the United States. Deployment of two satellites (each with 30m resolution and 7 spectral bands) under cloud-free conditions, would generate roughly 2×10^{11} bits daily, on the average. By comparison, the SEOS estimate ranged from 7×10^{9} to 7×10^{10}, Shuttle, 3×10^{10} and aircraft, 1.5×10^{10} to 8×10^{10} bits daily. It was thus concluded that further consideration in this study be directed toward polar orbiters only. However, current and future cost/benefit studies could reverse this conclusion if the aircraft prove cost effective relative to satellites and their roles were similarly emphasized.

SECTION 4.0
USER REQUIREMENTS

The need to reduce the time between observation and data availability to the user as from the current period of weeks to, in some cases, days has been frequently stated [1]. Numerous prior studies have been directed toward determining user requirements for earth-resources data. These include:

a) General Electric, Definition of the Total Earth Resources System for the Shuttle Era; November, 1974.
b) Operations Research, Data Origination and Flow for Advanced Earth-Sensing Satellites in 1985 and Beyond; June, 1975.
c) ERIM, Multispectral Scanners Data Applications; December, 1972
d) NASA, Advanced Scanners and Imaging Systems for Earth Observations; December, 1972
e) NASA, Earth Observation Satellite Payload Discussion Group,
f) Washington University, Remote Sensing Data User by State Agencies and Related Organizations; December, 1974.

While these studies were generally conclusive and detailed, they did not result in a firm consensus on specific spatial and spectral resolutions, timeliness, or frequencies of demand by either discipline or user institution. Important to the thrust of this study was the need to identify potential users that would require data within a few days of observation. Such users would provide the basic demand for maintaining a digital processing and transmission network that would substantially reduce the data delivery time.

Accordingly, numerous current users of LANDSAT data were interviewed for their options on data timeliness and resolution requirements as well as the efficacy of interaction with quick-look and archival data. Again, a consensus was lacking, particularly on timeliness and resolution needs, though a general dissatisfaction with current data delivery times was prevalent. In addition, frequent support was stressed for user interaction with data involving quick-look, classification processing, and archives.

4.1 Introduction.

The user model derived in this study is parametric. The important variables (data volume, timeliness and probability of demand) can be modified as inputs to the network simulation. The development of this model proceeded in two phases. First, as a result of reviewing previous studies and interviewing numerous current users, a series of demands were projected for specific agencies. These demands were predicated for each LANDSAT pass over the

continental U.S. and Alaska based on the coverage coincident with institutional areas of responsibility. This set of requirements is presented in this section. Second, two specific models, representing a nominal demand and an expanded demand, were derived from these potential requirements. These demands are presented in Section 5.0.

4.1.1 Current User Demand: LANDSAT data products are currently distributed by three federal government agencies: Department of Interior Earth-Resources Observation Systems (EROS) Data Center (Sioux Falls, SD), Department of Commerce, Environmental Data Service (Camp Springs, MD), and the Department of Agriculture, Aerial Photographic Field Office (Salt Lake City, UT). Of these, the EROS Data Center distributes the far larger portion of total data sales. Table 4-1, taken from an address by Al Watkins [2], Director of the EROS Data Center, indicates the sales of earth resources products by type, year and dollar value. The percentages of purchases by institution, also taken from that address, appear in Table 4-2.

Table 4-1

EROS Product Sales

	FY 73			FY 74			FY 75		
	Frames	Dollars	Average Dollars per Frame	Frames	Dollars	Average Dollars per Frame	Frames	Dollars	Average Dollars per Frame
LANDSAT Imagery	81,071	228,042	2.81	157,178	528,514	3.36	185,000	792,000	4.28
LANDSAT CCT's	10	1,600	160.00	228	36,480	160.00	820	164,000	200.00
Aircraft	83,942	144,676	1.71	109,490	237,332	2.16	193,000	520,000	2.69
Ratio Aircraft to LANDSAT Products	1.04			0.70			1.04		

Table 4-2

EROS Customer Profile - April 1974-March 1975

	All Products By Item	Landsat Products By Item
Private Industry	34%	24%
Foreign	12%	24%
Federal Government	27%	15%
Academic	14%	14%
Individuals	7%	10%
State & Local Govt.	1%	1%
Unknown	5%	12%
	100% = 413,776 frames	100% = 176,000 frames

CCT's 1.2% of total frames

It should be noted that the dollar value of EROS products covers the cost of reproduction only, not including the total EROS Center costs, NASA operating costs associated with data reception, satellite operational costs, data transfer from reception sites to the central data center, National Data Processing Facility (NDPF), and correctional processing costs including NDPF operations. In addition, the amortized costs of the satellites are not included in the cost of reproduction.

Considering EROS costs alone, in FY 1973 as indicated in Table 4-1, this facility received approximately $374K in reimburseable funds from product sales. According to the 1974 Annual Budget of the U.S. Government, about 7.69 million dollars were authorized for EROS during FY 1973 leaving a deficit of approximately 7.32 million dollars. When spread evenly over the number of frames sold that year, this amounts to a subsidy of $44.36 per frame compared to an average price of each LANDSAT frame of $2.81. Using actual sales for FY 1975 ($1,476,000) taken from the Watkins paper and estimated allocation for FY 1975 ($7,500,000), reported in the budget, the average subsidy per frame is $15.90 compared to an average cost per LANDSAT frame of $4.28. This approximately 4-to-1 subsidy may reflect the high cost of handling photographic products which could possibly be reduced by a digital data system. When all subsidized costs are considered, the presence of the large private demand (Table 4-1) is understandable. Any projections of future demand are made uncertain unless cost allocation to the users is specified. If cost per product should rise, future demand, particularly in the private sector, should diminish.

Current LANDSAT-2 investigations may result in increased demand as various institutions, domestic and foreign, determine positive results. At this writing, there are 109 individual LANDSAT-2 investigations of which 57 are domestic and 52 involve foreign nations. Forty-three U.S. state governments and 35 foreign countries are participating in these investigations. The number of investigations by discipline are given in Table 4-3.

Table 4-3

Current LANDSAT-2 Investigations

Agriculture/Forestry/Range Resources	22
Land Use	26
Geology and Mineral Resources	20
Water Resources	13
Marine Resources	9
Meteorology	4
Environment	11
Data Interpretation	4
TOTAL	109

4.1.2 Future User Demand: A purpose of this study was to evaluate the network options for rapid data dissemination of domestic earth-resources data. The implication is a demand for timely data that cannot be serviced by the mails. Thus, an important phase of the user interviews was to isolate applications that would require delivery of preprocessed data in periods of 5 to 9 days, or less, after the observation.

Several rapid-data turn-around applications were cited, predominant examples being:

1. Emergency assessment
2. Data that may result in enforcement action
3. Snow-melt predictions
4. Ice monitoring
5. Insect or disease detection in crops or forests
6. Water management as, for example, irrigation
7. Large area range management
8. Location of commercial fish
9. Intra-agency dissemination

In effect, the above applications, and perhaps others, would serve to justify a data dissemination network.

In view of the potential importance of these applications, it is of interest to review the jurisdictional responsibility and timeliness requirements for each.

4.1.2.1 Emergency Assessment: Emergencies include hurricanes, tornadoes, forest fires, insect outbreaks, earthquakes and floods. Each of these involve common and different agencies. Satellite-derived data has proved useful in assessing resulting damage for each of these events [3] except infestation of crops, a subject requiring continued research.

Widespread agency involvement implies overlapping jurisdiction; federal, state and private. However, the one political unit common to all emergencies is the state government. It would thus seem reasonable to assume that the state Civil Defense Agencies or the equivalent would most likely be the central user of remotely-sensed data.

Naturally, it is desirable to obtain this data as soon as possible. If a priority structure were established throughout the network, 1985 technology could provide this data within a matter of hours after observation. SEOS (100m resolution) data would be delayed only by cloud cover. In the event that agricultural damage resulted, a second assessment seems desirable. Immediate damage assessment of crops tends to overstate damage [4]. A second survey approximately one week after damage would allow the crop to stabilize and thus serve more properly as a source of mensuration data. In this case, timeliness would be less critical.

4.1.2.2 Enforcement: Satellite data has proved useful in detecting and monitoring various forms of water pollution as well as damage resulting from and reclamation efforts related to strip-mining. Both circumstances require corroborative field investigation and, thus, require timely data delivery.

Water surveillance involves much agency overlap. For example, if pollution results from a structure or an operation such as dredging, the Corps of Engineers is involved. If resulting from coastal or off-shore mineral extraction, the Bureau of Land Management is involved. If an oil spill, the Coast Guard is responsible. The Environment Protection Agency is responsible for all forms of pollution. Finally, if in coastal or inland waters, State Environmental Protection agencies are involved. This overlap of responsibility may create multiple demands for the same data.

Monitoring strip-mining operations, typically, is within the jurisdiction of the State Environmental Agency. However, the federal EPA could also become involved, depending on the specific federal/state relationship.

4.1.2.3 Snow Melt: River flow rates and heights are now being predicted by computer models. One term in some models is the snow depletion factor.

Satellite data has proved useful as a check on this factor [5]. Data consisting of three or four bands at relatively course resolution (80m) is required no later than 72 hours after observation [6]. Delivery within 24 hours is preferable.

River estimates involve jurisdictional overlap between NOAA National Weather Service, River Forecast Centers, Soil Conservation Service, Corps of Engineers, Bureau of Reclamation, Power Administrations and State Departments of Water Resources. Currently, these responsibilities have been assumed on a geographical basis. Data dissemination, if implemented, would likely involve several agencies.

4.1.2.4 Ice Monitoring: Ice hazards to ship traffic in coastal waters and the Great Lakes have traditionally been the responsibility of the Coast Guard. The development of the oil fields in the Arctic have significantly emphasized the importance of this data. Areas of particular importance are the Arctic Ocean, Bering Sea off western Alaska, and the Davis Strait off Greenland. There are potentially hundreds of private users due to the commercial activity in the Arctic. Some form of common use involving either federal agencies or a private consortium is most likely. Of particular importance is the extent of allowable operations. Figure 4-1 depicts maximum and minimum sea ice advance and retreat off Alaska.

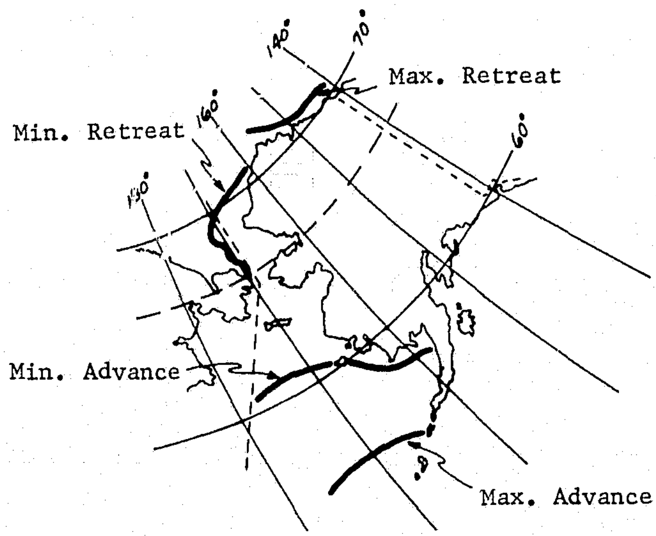


Figure 4-1 Seasonal Alaskan Sea Ice Movement

Sea ice data is required daily on a near-real-time basis. It is anticipated that this data would involve transmission to ships at sea. Currently, a ship traffic monitoring and weather advisory facility is being considered by NOAA in the Seattle region. Such a facility could provide the additional service of sea ice status. Thus, jurisdictional involvement in this application could include NOAA, Coast Guard and/or a private consortium.

4.1.2.5 Insect or Disease Detection: Detection of large-area infestation of forest lands with satellite data has been demonstrated [7]. The potential of detection of insect infestation in crops is uncertain and yet requires much basic research. Either application requires data delivery within one or two days of the observation.

Likely users of forest data include the USDA Forest Service, state Forestry Departments and perhaps private users in the paper and wood industry. If infestation detection in crops should eventually prove successful, then the USDA and state agricultural departments could be users.

4.1.2.6 Water Management: Irrigation is one of the largest water uses in the United States. As mineral extraction increases in the western states, competition for water resources with agricultural interests will become acute. There is some controversy relative to the value of satellite data as a means to estimate the area of standing water. While this measurement

has been technically demonstrated on LANDSAT experiments and, in fact, implemented on the Pacific Northwest Regional Commission program at Ames Research Center, the applicability, particularly on a timely basis, would likely be limited to remote (hence, relatively small) bodies of water. For example, the Bureau of Reclamation maintains the primary responsibility in 17 western states for delivery for irrigation. However, their water levels are now accurately monitored. Satellite data would be useful for measuring the area of irrigated lands rather than the area of impounded water. Thus, the primary user relative to irrigation would be the Bureau of Reclamation. Possible user institutions include the Corps of Engineers, regional water districts and State Departments of Water Resources.

4.1.2.7 Range Management: Currently, the Bureau of Land Management prepares a forage estimate of certain grazing lands every two weeks during the appropriate seasons. The Bureau of Land Management is responsible for approximately 570 million acres, mostly in the western states. They, typically, have only one resources manager for approximately one million acres; thus, remotely-sensed data is their only means of obtaining up-to-date information on large range areas. As the forage estimates may affect cattle density allotments, data delivery within two or three days is desirable. Other agencies to which this application may apply include the Bureau of Indian Affairs and State Agricultural agencies.

4.1.2.8 Commercial Fish Location: Sea surface temperature has been correlated with the location of certain commercial fish species such as the tuna [8]. In addition, research in the Gulf Coastal areas has indicated correlation between water turbidity and menhaden schools [9]. High spatial resolution data is not essential for this application as 1/2- to 1-km resolution data appears sufficient. However, timeliness measured in one to two hours is essential. Again, the cyclic periods of polar orbiters severely hamper this application suggesting the potential use of SEOS data or perhaps the addition of a higher spectral resolution visible load on GOES-type satellites. In the event that this application would become operational, NOAA would likely provide this function at two to three centers separately servicing the Atlantic, Gulf, and Pacific coasts.

4.1.2.9 Intra-Agency Data Dissemination: Certain agencies will disseminate data over internal networks to local and regional facilities. As this function, which may include data processing, will require time, early receipt of data becomes a requirement. An example, is the Department of Agriculture which may introduce a centralized data bank from which data can be disseminated to the county level. When this requirement is coupled to the potential application of early infestation detection, then a short timeliness of large data volumes is implied.

4.1.2.10 Competing Sources: Data sources, other than satellites, can provide the data associated with the aforementioned rapid-turn-around applications. For example, synchronous

meteorological satellites, such as the GOES or advanced versions (SEOS), can support snow-melt predictions, mid-latitude ice monitoring, and location of commercial fish. Similarly, polar orbiting meteorological satellites or SeaSat satellites can support snow-melt predictions, ice monitoring, water management, and location of commercial fish. In addition, aircraft, if cost effective, could support any of the foregoing applications. The implication is that a data dissemination network would prove most cost effective if selected data from different sources could be passed on to the network. Accordingly, the user models which follow were based on relatively large earth-resources data demand. The conclusions of this study, relative to network selection, apply even though portions of the earth-resources data are replaced by other data.

4.2 Model Variables.

The variables that impact the data dissemination network are: data volume, timeliness requirements, and frequency of demand. These are discussed in this section. Certain assumptions are implicit in structuring these variables. With one exception, it was assumed that all users would receive data consisting of a full swathwidth with variable along-track length. This assumption represents a compromise between the current practice of providing products in increments of full scenes (100 n.mi. by 100 n.mi.) and the likely practice, easily obtainable with a digital system, of providing sectors of any size as requested. Sector dissemination would substantially reduce the data volume at least at the user facility. This reduction is demonstrated in Appendix B in which the total data volumes, in pixels, associated with Corps of Engineers Districts is given for dissemination of full LANDSAT scenes and dissemination of fractions of scenes (with full swath). In both cases, this data is given for coverage by Corps Districts over a four-day period. The data required for fractional scenes (full-swath width) typically varies between 44% and 50% of data volume for full-scene dissemination. Sector dissemination would represent a greater measure of volume reduction. In addition, it was assumed that all users would demand the best resolution available.

4.2.1 Data Volume:

The data volume to each user is determined by the spatial resolution, number of spectral bands, and area requested.

The assumption that each user will demand the best available resolution bounds this parameter at either 30m or 10m, depending on the data input selected (see Section 3.2). There is a general belief that improved resolution, as from 30m to 10m, will result in increased demand for products; however, the increased cost of data processing associated with data volume alone should dampen this demand. Nevertheless, an increase in number of users can be expected. For example, 10m data might prove adequate for location and cyclic monitoring of site-specific pollution and/or nutrient sources entering water. If so, state environmental agencies would more aptly justify the need for remotely-sensed data. Thus, the number of

users (or, rather, extent of demand) should be inversely proportional to spatial resolution.

The number of available spectral bands is either seven or twelve depending on the data input selected. However, it would be unrealistic to assume that all users will demand all available bands. Thus, a number of spectral bands was associated with each user. Although the number of spectral bands demanded by a given user was constant, variation in data volume was achieved by varying the area of coverage demanded.

Projections of area demands were based on institutional jurisdiction. For a given orbit pass, the area associated with an institutional responsibility was calculated as a length in the along-track direction. Either that area or a fraction thereof was represented as a demand. For example, demands from the Army Corps of Engineers District in Boston were modeled for those orbits passing over that district. For the ERTS/LANDSAT orbits, this user represented a potential demand for four consecutive days and, hence, no demand for the following 14 days. In some cases, however, jurisdictional responsibility is segmented, or is generalized over large areas, examples being the Environmental Protection Agency, Coast Guard, and Regional Commissions. In these cases, either a standard percentage of the total path was assumed or multiples of the standard ERTS scene (100 n.mi. by 100 n.mi.) were assumed.

The question of transmission format has significant impact on the area estimates. Currently, data products are delivered in scene formats 100 n.mi. by 100 n.mi.. A single scene can be delivered on one, two or four computer-compatible tapes. One means of area estimate could be based on scene transmission where each fraction of area requires a full-scene transmission. Given a digital dissemination network, sector data could be selected for only those sectors required by the user. This approach would substantially reduce the user data load. The scene estimate represents the maximum data load, whereas a sector estimate would represent the minimum data loads. The approach in this study is a compromise of these extremes. In this approach, it was assumed that the transmission format would consist of the full-swath width east/west and any 5-n.mi. segment north/south with a minimum of 25 n.mi. per transmission.

4.2.2 Time Requirements: The essential requirement for a data dissemination network will result from a justifiable demand for data products at about nine days or less. For periods in excess of that amount, distribution by mail will suffice. This model, therefore, only generates demands for data that is required within nine days.

Choices of timeliness requirements used in this model were based on the individual user interviews. These were, however, varied for most users to allow investigation of the impact of the user timeliness demand on transmission link capacities and processing throughputs. In all cases, timeliness was entered in multiples of 24 hours; either as 9, 5, 2, or 1 day(s).

4.2.3 Probability of Demand: A demand projection for remotely-sensed data is dependent on overriding factors such as the state of the economy, relative social priorities, and advances in specific supporting technology. In order to accommodate this uncertainty, the demand model was constructed so that individual users or classes of users could be incorporated or removed from the demand. In addition, their demand is stated in terms of probability. The probability of demand is defined as the probability, on a given orbit pass, that a specific user will generate a demand. This does not include the probability that a user will actually enter a direct transmission service. A user demand may be scheduled or unscheduled. If scheduled, it could be stated as a requested coverage over a specified period of time. Alternatively, the request could be stated for a particular time period; i.e., the second week in June. If unscheduled, the request could be random or, alternatively, dependent on an outside event that could be statistically predicted, such as a natural disaster. These alternatives are described by examples below:

Demand Type	Example
Scheduled repeat cycle	Once every 30 days
Scheduled time window	June 1 to June 20, July 5 to July 16, etc.
Unscheduled outside event	Hurricane damage assessment
Unscheduled random	Verification of suspected pollution source as soon as possible

For scheduled time windows, the probability of demand equals the probability that any orbit will traverse the selected path. However, given the deterministic nature of orbits, rational users will select windows coincident with orbit paths. Thus, for this case, the probability of demand will be either one or zero.

In this study, the probability of demand was modeled for scheduled repeat cycles only. The The probability of demand for this case is a function of the number of satellites, the coverage cycle, and the frequency of update. This is calculated in the following paragraphs.

Let the observation repeat cycle be signified by x and the satellite orbit repeat cycle by m. For equally weighted orbits, the probability of demand for any orbit would be the reciprocal of the number of orbits during the observation repeat cycle. However, for any period in excess of the orbital repeat cycle, there are two possible numbers of orbits depending on the satellite phasing. For example, for an 18-day-orbit cycle and a 30-day-coverage cycle, the satellite will orbit any particular path either once or twice in 30 days. Similarly, for a 176-day coverage cycle, a single satellite will orbit a particular path either five or six times.

Introducing the notation $(x/y)_{tr}$ to mean truncation of the term x/y to the integer, the number

of possible orbits is $(x/m)_{tr}$ or $(x/m)_{tr} + 1$. Given a repeat coverage cycle, the proba- of bility of demand for any orbit path can be expressed as the linear combination

$$P_D = \frac{a}{(x/m)_{tr}} + \frac{b}{(x/m)_{tr} + 1}$$

where:

a = probability of the minimum number of passes

b = probability of the maximum number of passes

Clearly, if $x < m$, $P_D = 1$ as the satellite will cross the path, at most, one time.

If $m \leq x \leq 2m$, then the number of days in the period, m, for which the maximum number of orbits occur is x-m. The number of days in the period m for which the minimum number of orbits occur is $m-(x-m) = 2m-x$. Thus, the probabilities a and b can be expressed:

$$a = \frac{2m - x}{m} \qquad b = \frac{x - m}{m}$$

Hence: $$P_D = \left(\frac{2m - x}{m}\right)\frac{1}{(x/m)_{tr}} + \left(\frac{x - m}{m}\right)\frac{1}{(x/m)_{tr} + 1}$$

If $x > 2m$, the coefficients a and b are inappropriate; i.e., negative probability. This can be corrected by introducing the variable, y, such that:

$$x = y - \left\{(y/m)_{tr} - 1\right\} m$$

where y = requested repeat cycle $> 2m$.

This adjustment maintains the condition $m \leq x \leq 2m$.

The probability of demand for a scheduled repeat cycle is, thus:

$$P_D = \left(\frac{2m - y + [(y/m)_{tr} - 1]\ m}{m}\right)\frac{1}{(x/m)_{tr}} + \left(\frac{y - [(y/m)_{tr} - 1]\ m - m}{m}\right)\frac{1}{(x/m)_{tr} + 1}$$

The following table gives the probabilities of demand for several repeat cycles for a single satellite with an 18-day coverage cycle:

P_D	Repeat Cycle (days)
1	7
1	14
0.722	28
0.666	30
0.305	60
0.123	120
0.049	365

The above values, adjusted for multiple satellites, were used in the demand model.

4.3 Potential Network Users.

This section presents a discussion of potential direct network users by institution. As stated in the introduction of this section, the derivation of user models for simulation involved a two-step process. First, a set of potential users with associated demands was postulated. The results of this step are given in this section. Next, specific demand models are organized from the potential sets. These models, of which two were used in the subsequent simulations, are presented in Section 5.0.

In order to simulate the timing constraints introduced by the periodicity of polar orbiters, each institutional demand was estimated on a per-orbit basis. That is, for each orbit pass, the required coverage for the area of responsibility was estimated for each institution. In some cases, such as the Environmental Protection Agency, the responsibility extended over the entire United States. In these cases, either a percentage of the total swath or some number of scenes per orbit was assumed.

Both the current LANDSAT orbit and a lower altitude LANDSAT-D orbit were investigated. The LANDSAT-D orbit represented slightly greater than 7% increase in potential data load. However, due to the familiarity of the current orbit, these orbits were used to develop demand by orbit pass. Figures 4-2 and 4-3 illustrate the current LANDSAT orbits over continental United States and Alaska, respectively. Appendix B of the report presents the potential demands by orbit.

The following passages indicate the reasoning used to develop the potential institutional demands given in Appendix C.

4.3.1 Federal Government:

4.3.1.1 Introduction: There is a mixed reception for satellite-derived remotely sensed data, both within and between federal agencies. Certain agencies such as the Bureau of Land Management and the Army Corps of Engineers are actively considering regional processing centers. Others such as the Environmental Protection Agency reflect a more conservative attitude. A summary of some negative views concerning the utility of satellite data was given during the testimony of Frank Zarb [10] representing the Office of Management of the budget before the Committee on Aeronautical and Space Sciences, September 18, 1974. The following comments are excerpts:

> "....we have found so far is that a majority of present users are one-shot lookers. Once overflights have taken place and oil users or the mineral users can take a look at that part of the geography with several images at the current resolution, they have had it until the next generation of information...."

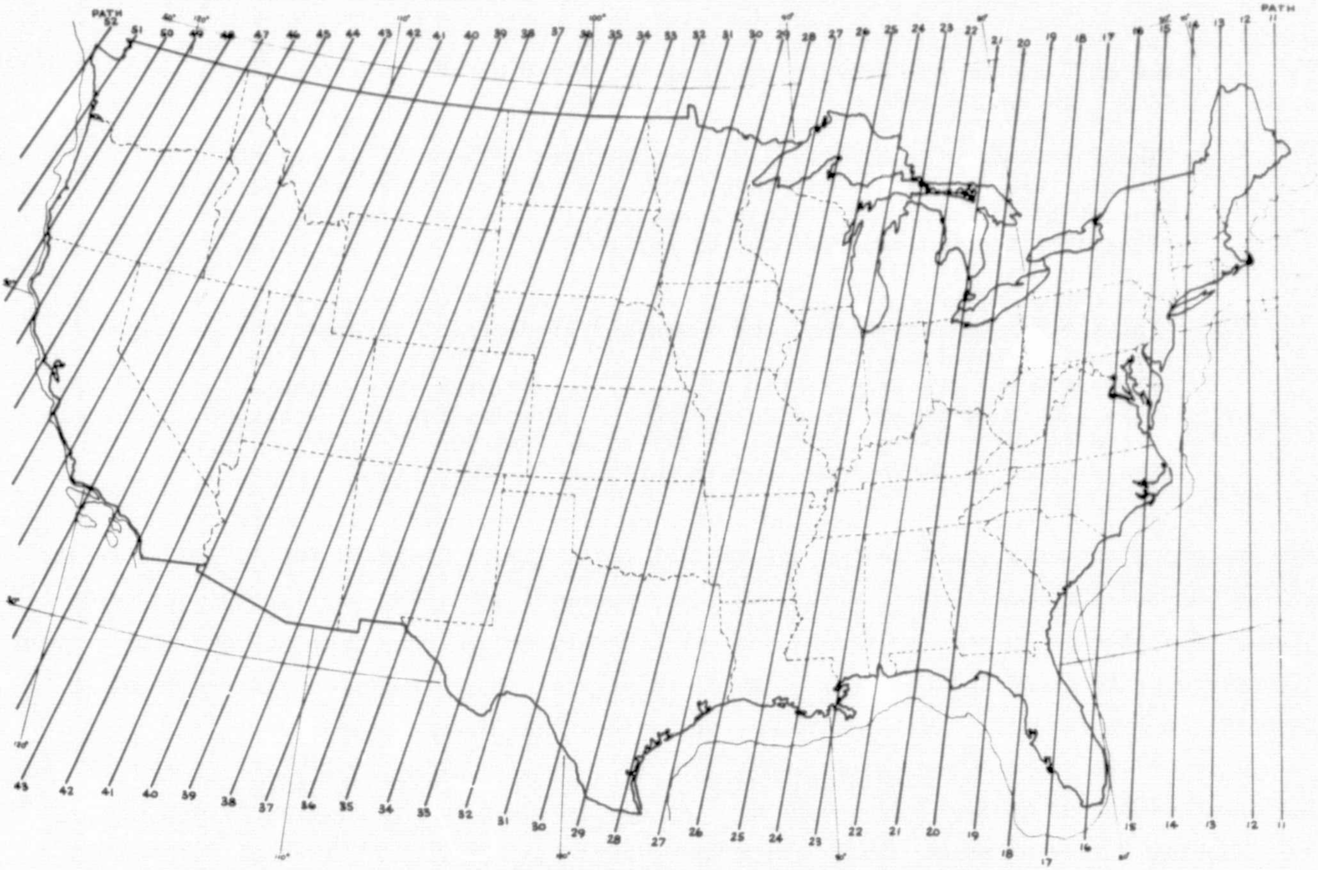


Figure 4-2. Standard LANDSAT Swaths - CONUS

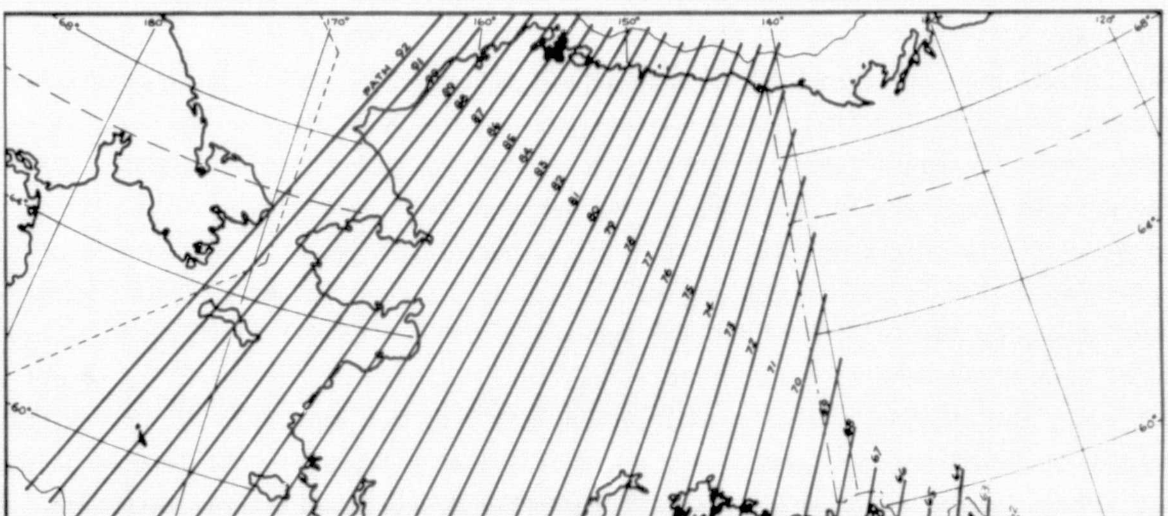


Figure 4-3. Standard LANDSAT Swaths - Alaska

"without significantly improved resolution....there is no possible way the ERTS system can achieve any improvements over the existing crop forecasting system."

"The Forest Service commented by saying that: 'There is as yet no demonstrable need in forest inventory, the apparent major area of benefit in forestry, for frequent acquisition of the relatively low resolution information produced by ERTS.'"

"The Office of Research and Development of the EPA commented that: 'For the simple reason that the essential elements of information for environmental monitoring are numerous and often subtle, it is imperative the EPA acquire imagery, ...at very high resolutions. While some benefit may be derived from the examination of low resolution imagery, the great bulk of essential elements of information... lies well below the 30-foot ground resolved distance...'".

The preceding comments apply to current LANDSAT resolution. Improved resolution reflected by the 30m and 10m models could well result in increased demand by the specific agencies cited. Any attempt to project federal use of remotely sensed data must contend with current divergence of opinions concerning utility of this data. An optimistic estimate based on favorable opinions will defeat the intent of a model that bounds actual use.

The total number of federal users will be largely dependent on the degree of inter-agency data sharing. Many agencies, both within the federal government and between federal and state governments, require a common data set for particular applications. For example, disaster assessment cuts across jurisdictions of many agencies. In the case of flooding, state agencies state crop planting may be changed and, of course, state civil defense agencies require data to coordinate evacuation and relief. The Army Corps of Engineers requires the same data for flood control decisions and the Department of Agriculture might use similar data to assess damage impact on crops. Behind each of these agencies stand numerous private institutions including relief agencies, and transportion, fertilizer, insurance, and agricultural companies. If each potential user were to initiate independent processing facilities, a substantial demand could develop. The extent of data sharing will be paced largely by the actions of federal agencies. This is difficult to predict; not only because of likely disputes on organizational charters but also due to differing output product demands; e.g., the USDA would require multi-band data sets (or subsets). In effect, the earth-resources-data demand will be governed by the division of responsibilities within federal agencies and by resolution of the historically controversial state/federal interface. The large amounts of data involved with the implied processing costs will seem to support the development of regional or district processing operations.

4.3.1.2 <u>Department of Interior</u>: Several Interior agencies appear to be possible users of satellite-derived data on a timely basis. These include the Geological Survey, Bureau of Land Management, Bureau of Indian Affairs, and the Bureau of Reclamation. Other potential

users within the Department include the U.S. Fish and Wildlife Service, any of the five Power Adminsitrations and the National Park Service. However, there is no specific requirement with these latter agencies for a rapid turn-around time. Possible exceptions include the Fish and Wildlife Service which may use such data to support annual game/fowl migration estimates; also, the Power Administrations, particularly Alaska and Bonneville, can use satellite-derived data to estimate snow depletion rates. However, this data can be made available from other federal agencies such as the National Weather Service or Corps of Engineers. Thus, no demand was modeled for these agencies.

Geological Survey: The Earth Resources Observation Systems (EROS) Data Center at Sioux Falls is currently responsible for distributing earth-resources products to users. Associated with this activity are Applications Assistance Facilities and Cartographic Information Centers; these facilities are located at Reston, Virginia; Rolla, Missouri; Bay St. Louis, Mississippi; Phoenix, Arizona; Denver, Colorado; Menlo Park, California; and Fairbanks, Alaska.

In order to support potential users that require timely data but do not have reception facilities, data receipt at EROS would have to be timely. This raises the question as to whether a model of this demand should reflect reception at a central facility (Sioux Falls) or additional reception at the aforementioned centers. In view of the existing EROS information network, it was decided to model the Sioux Falls facility as the single recipient of data. Due to the primary responsibility of this agency to distribute data products, it was estimated that all data over the outer continental shelf and land and all spectral bands would be provided to Sioux Falls. Thus, the probability of demand for each swath would be 1.0. In order to test the impact of this demand, three separate timeliness requirements were assumed; five, two and one day(s). These are obviously exclusive demands; that is, only one timeliness would be used in a given simulation. The summary of these potential demands is shown below:

Location	Length	Bands	Timeliness	Probability of Demand
Sioux Falls	all land and OCS	all	1	1.0
Sioux Falls	all land and OCS	all	2	1.0
Sioux Falls	all land and OCS	all	5	1.0

Bureau of Land Management: The Bureau of Land Management is responsible for about 500×10^6 land acres and approximately the same area over the outer continental shelves. The substantial portion of land is in twelve western states that are served by eleven state offices. These, plus four outer-continental-shelf offices, would constitute potential centers for reception and data processing.

The potential data demands differ for state offices and outer-continental-shelf (OCS) offices. A predominant demand by the state offices will be to evaluate range conditions. Currently, a nine-day delivery period is desired for this data. However, one application cited [11] was to use remotely sensed data to support current two-week forage estimates. These estimates frequently influence decisions of private ranchers leasing BLM property. In this instance, data would be required more rapidly than nine days.

A primary responsibility of the four OCS offices is to monitor the impact of mineral production activities on the continental shelf and wetlands. Substantial production efforts on the shelf are expected within the next decade; examples being sand and gravel extraction, phosphate mining, and oil and gas exploration. Remotely sensed data could be used to monitor sediment and thermal plumes and, possibly, oil spills. A-priori knowledge of the location of activity could limit the total area scanned to specific sectors. However, if intensive mining developments are expected, then surveillance monitoring might be desirable.

Based on the foregoing considerations, the following demand was modeled for the BLM. For the state offices, the total area of BLM responsibility was assumed as a demand for either 9-day or 2-day timeliness. In addition, 10% of BLM area was modeled for 2-day timeliness. These potential demands allow simulation of full land monitoring and classification with rapid or relaxed turn-around conditions as well as rapid surveys of limited land areas. Currently, BLM analysis is using all four LANDSAT bands. The potential advantages of additional bands are uncertain. Thus, a standard demand of six bands was assumed. It is likely that this assumption will tend to overstate data volume.

The outer-continental-shelf offices were assumed to require all continental-shelf data within 5 days and 2 days and 20% of the continental shelf in 5 days. The former set represents a surveillance mode while the latter demand represents specific sector monitoring. Except for Alaska and paths 17 and 18, the data per swath delivered to OCS offices would consist of an equivalent LANDSAT scene or less. This suggests a single processing center for CONUS. If the Anchorage office were to attempt surveillance of the entire Alaskan continental shelf, a separate Alaskan facility might be warranted. Nevertheless, four reception centers (New York, New Orleans, Los Angeles, and Anchorage) were modeled. The OCS office demand for spectral bands should be less than the state office demand. Thermal plumes can be detected with a single infrared band while sedimentation could be detected with two, and perhaps one, visible bands.

In addition to regional offices, a cumulative demand for all BLM data was assumed for the Washington area. Thus, on a given swath, the total BLM demand is delivered to the Washington area. A summary of the assumed BLM demand follows:

Location	Length	Bands	Timeliness
State Offices	all BLM land	6	5
State Offices	all BLM land	6	2
State Offices	10% BLM land	6	2
OCS Offices	all continental shelf	4	5
OCS Offices	all continental shelf	4	2
OCS Offices	20% continental shelf	4	2
Washington	state office cumulative	6	5
Washington	state office cumulative	6	2
Washington	state office cumulative	6	2
Washington	OCS office cumulative	4	5
Washington	OCS office cumulative	4	2
Washington	OCS office cumulative	4	2

Figures 4-4 and 4-5 depict general areas of BLM management responsibility for CONUS and Alaska, respectively. Orbit path overlays (Figures 4-2 and 4-3) were used to determine demand for each path.

Bureau of Indian Affairs: Currently, the BIA is using remotely sensed data for land-use classification; in particular, involving the Olympic peninsula in the state of Washington. Anticipated use of remotely sensed data includes change detection monitoring of Indian lands, these comprising about 54×10^6 acres. Direct data reception, if implemented, might be organized through five or six regional centers that are tied to several hundred remote terminals. For the purposes of this model, reception centers were assumed at Albuquerque, Billings, Portland, and Minneapolis, with cumulative data on any given pass also delivered to Washington, D.C.

The primary purpose of remotely sensed data will be to develop land-use maps. Generally, this function would not require data reception within a few days of observation; however, the occurrence of natural hazards would accentuate the need for rapid data delivery. For this reason, data delivery in five or two days was assumed. It was also assumed that all Indian lands would be monitored in six bands. Figure 4-6 indicates reservation lands that were used with orbit overlays. Figure 4-5, shown previously, indicates reservation land in Alaska.

The summary of the assumed BIA demand is:

Location	Length	Bands	Timeliness
Regional center	all reservation land	6	5
Regional center	all reservation land	6	2
Washington	cumulative	6	5
Washington	cumulative	6	2

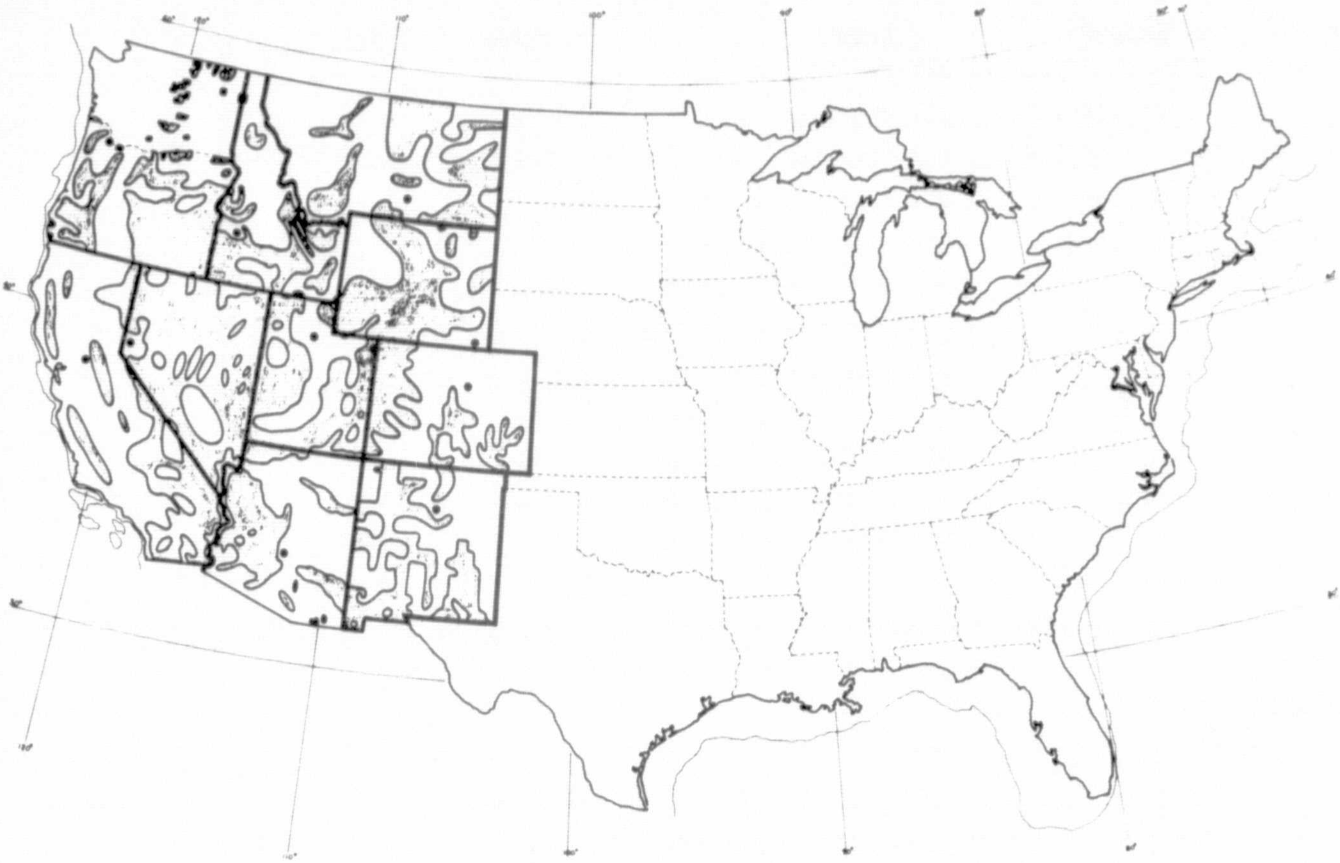


Figure 4-4. Bureau of Land Management District Areas and Estimated Land Areas

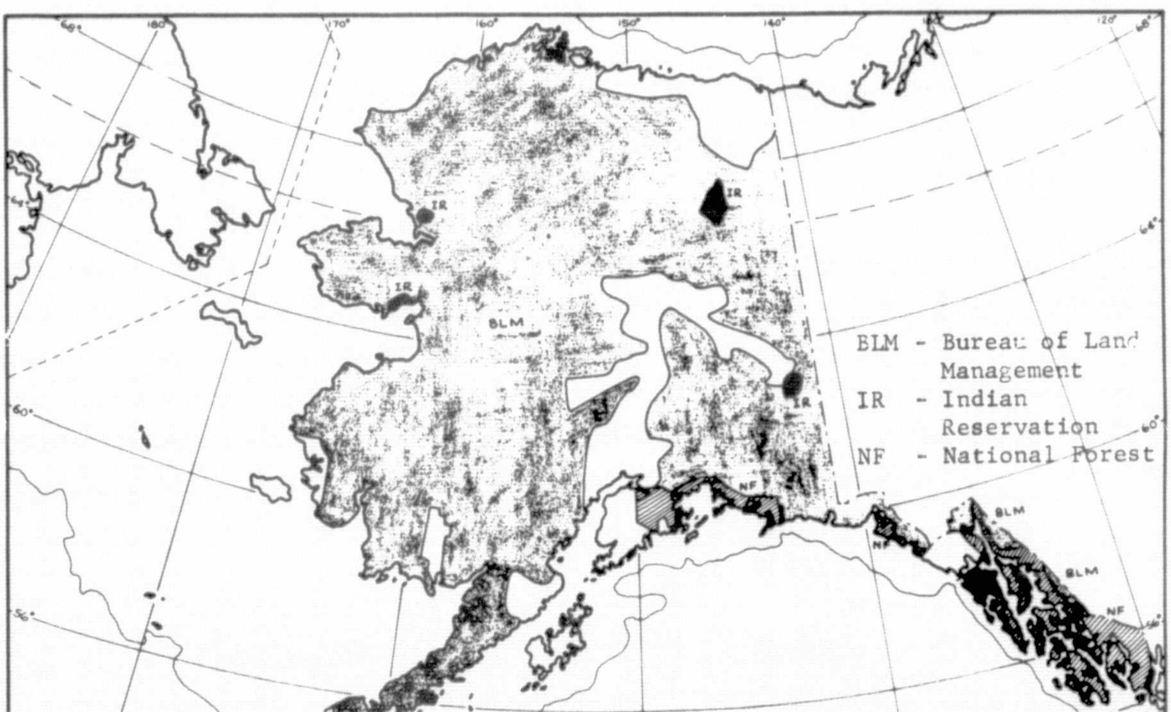


Figure 4-5. Federal Land Areas - Alaska

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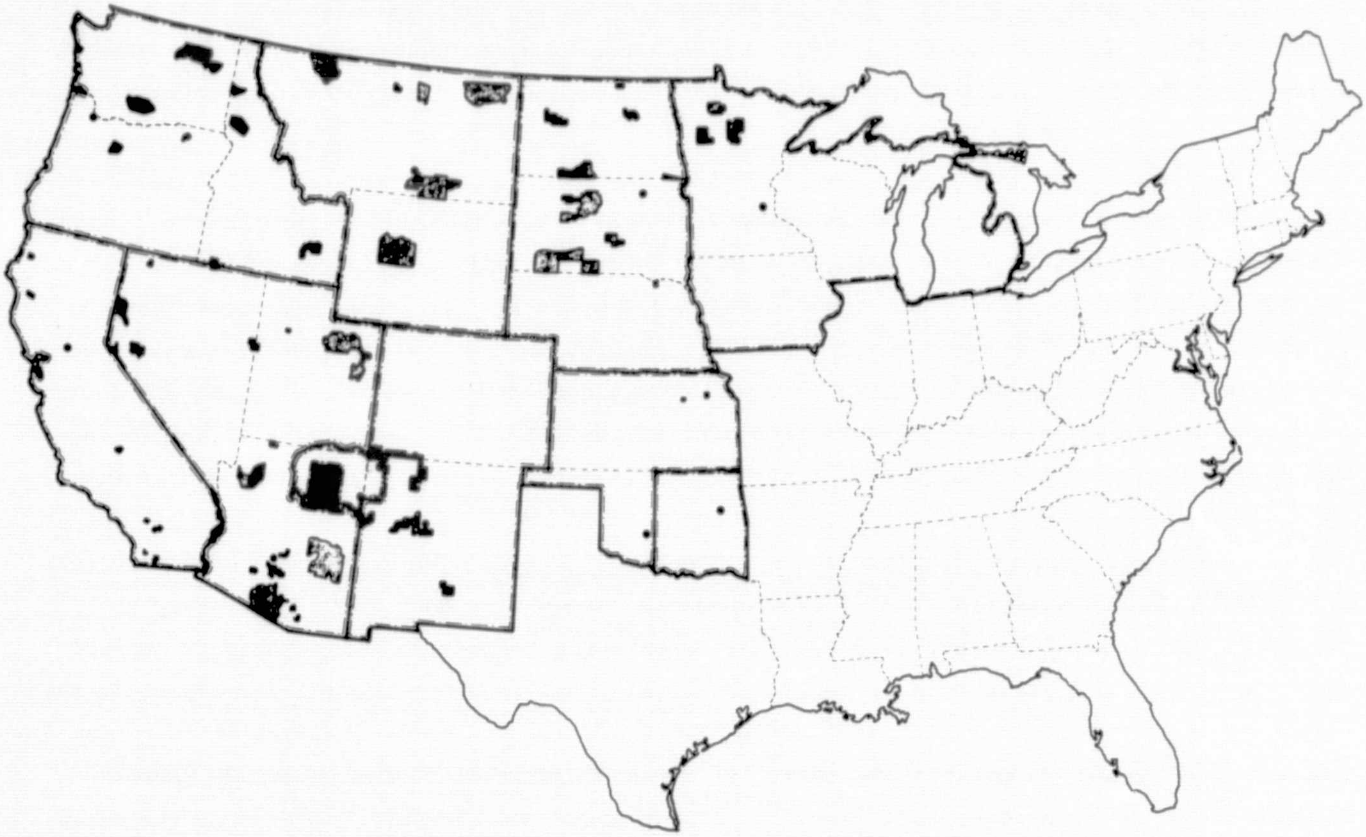

Figure 4-6. Indian Reservations and Bureau of Indian Affairs Districts

Bureau of Reclamation: The principal responsibility of the Bureau of Reclamation is to provide water resources development in the 17 western states. This includes construction of dams and water delivery for irrigation. This responsibility leads to a potential use of remotely sensed data to estimate current and future agricultural land under irrigation, a requirement involving a land-use classification specifically directed toward irrigated land mensuration. Mensuration of surface water, except for a few remote dams, is not a likely application as reservoir levels are now accurately gauged.

Data analysis would likely be performed at a single center located in Denver. The presence of several federal agencies such as the BLM in this city suggests that a combined regional operation may develop. However, a separate Bureau of Reclamation demand was modeled.

Current data delivery times hamper attempts to classify irrigation lands. A five-day delivery was suggested [12]. Thus, a five-day and one-day timeliness was assumed. Again, a demand for six bands was assumed. In summary, the Bureau of Reclamation demand is:

Location	Length	Bands	Timeliness
Denver	5% western lands	6	5
Denver	5% western lands	6	1

4.3.1.3 Department of Agriculture: Department of Agriculture agencies most likely to use remotely sensed data include the Agriculture Stabilization and Conservation Service (ASCS), Forest Service (FS), Soil Conservation Services (SCS), and the Statistical Reporting Service (SRS).

As may be noted, subsequently, the Department of Agriculture may centralize reception and distribution of remotely sensed data through a central facility. If so, a multi-user demand for the Department of Agriculture would overstate the actual load on a data dissemination network. On the other hand, certain types of transmission, such as by satellite relay, best serves multi-agency reception. Thus, a multi-agency demand was modeled, of which one demand involves the transmission of all data to a central facility. The Department of Agriculture demand can, therefore, be tailored for either multi-agency or single-agency demand or both.

Agriculture Stabilization and Conservation Service: The Department of Agriculture is currently distributing remotely sensed products through the ACSC Photo Laboratory at Salt Lake City. Consideration is being given within the Department of Agriculture to full data reception and distribution to the county level using existing federal networks. In this instance, it is anticipated that total U.S. coverage would be received with a 24-hour timeliness factor. This demand is essentially identical to the Department of Interior EROS Center demands discussed in Section 4.3.1.2. The ASCS demand was, therefore, modeled as the reception of all data, excepting the continental shelf, within one, two or five days.

The potential demands, Interior EROS and Agriculture ASCS, constitute the overriding requirement for a data dissemination network. A more thorough analysis would involve data dissemination within each agency. The satisfaction of these two requirements, particularly in one day, would typically result in satisfaction by most, if not all, other users. The summary of the ASCS potential demand is:

Location	Length	Bands	Timeliness
Salt Lake City	all land Alaska excluded	all	5
Salt Lake City	all land Alaska excluded	all	2
Salt Lake City	all land Alaska excluded	all	1

Statistical Reporting Service: The current technology of satellite-derived remotely sensed data does not seem adequate to compete with current techniques of crop estimation at the national level. However, given improvement in the technology in terms of coverage, resolution and available spectral bands, two factors may evolve a demand for this data. First, data on international crops involving other agencies such as the Department of State, may result in a global crop prediction effort. This application is modeled as the Crop Inventory Program. Second, even though national estimates are quoted at a 2% accuracy level, state predictions based on current sampling techniques are apparently considerably less accurate. Thus, cooperative federal/state efforts might develop at the state level using remotely

sensed data as the information source. This development would involve state-by-state stratified sampling and state-located processing facilities. This potential demand was modeled under the appropriate states as discussed in Section 4.3.2.

The objective of the Crop Inventory Program is to use imagery from satellites and weather data to predict crop production. This description of the CIP is based on the current Large Area Crop Inventory Experiment (LACIE) which NASA, USDA and NOAA are mutually conducting.

In LACIE, the LANDSAT imagery is received from GSFC in segments of 117 scan lines with 196 pixels to the line. Data is from 4 spectral bands and represents a ground rectangle about 8.7 km high (north-south dimension) and 11.2 km wide (east-west dimension). The total number of pixels for each band is 22,932. These segments are extracted at GSFC from the regular 100-n.mi. (1852-km) wide coverage strips received from LANDSAT 2 and registered to a reference segment so that multispectral, multi-temporal classification can be performed.

Table 4-4,"LACIE Segment Allotment", shows the allocation of LACIE segments for various countries planned at the beginning of the LACIE program.

Table 4-4

LACIE Segment Allotment

COUNTRY	SEGMENTS
Argentina	165
United States	638
India	638
Canada	288
Australia	259
China	813
USSR	1949
TOTAL	4750

The CIP demand presented here is the only exception to the full-swath-width area estimate as sector transmission was assumed. Approximately 20% of the LACIE segments are used as training segments. The remaining 3840 segments are to be sampled and classified four times a year. It was thus assumed for the CIP demand that 128 segments (training sites) plus 101 segments (16% of all 638 U.S. segments) would represent a potential spring or summer demand on appropriate passes. For the 9-km along-track segment dimension, this represents about 890 n.mi. over wheat land. Thus, 1000 nautical miles (along track) was allocated according to the wheat acreage as depicted in Figure 4-7.

The CIP segments were standardized at 9-km high by 11-km wide in 7 bands. For a 10-meter IFOV, each segment will be composed of 900 lines with 1100 pixels per line. This gives

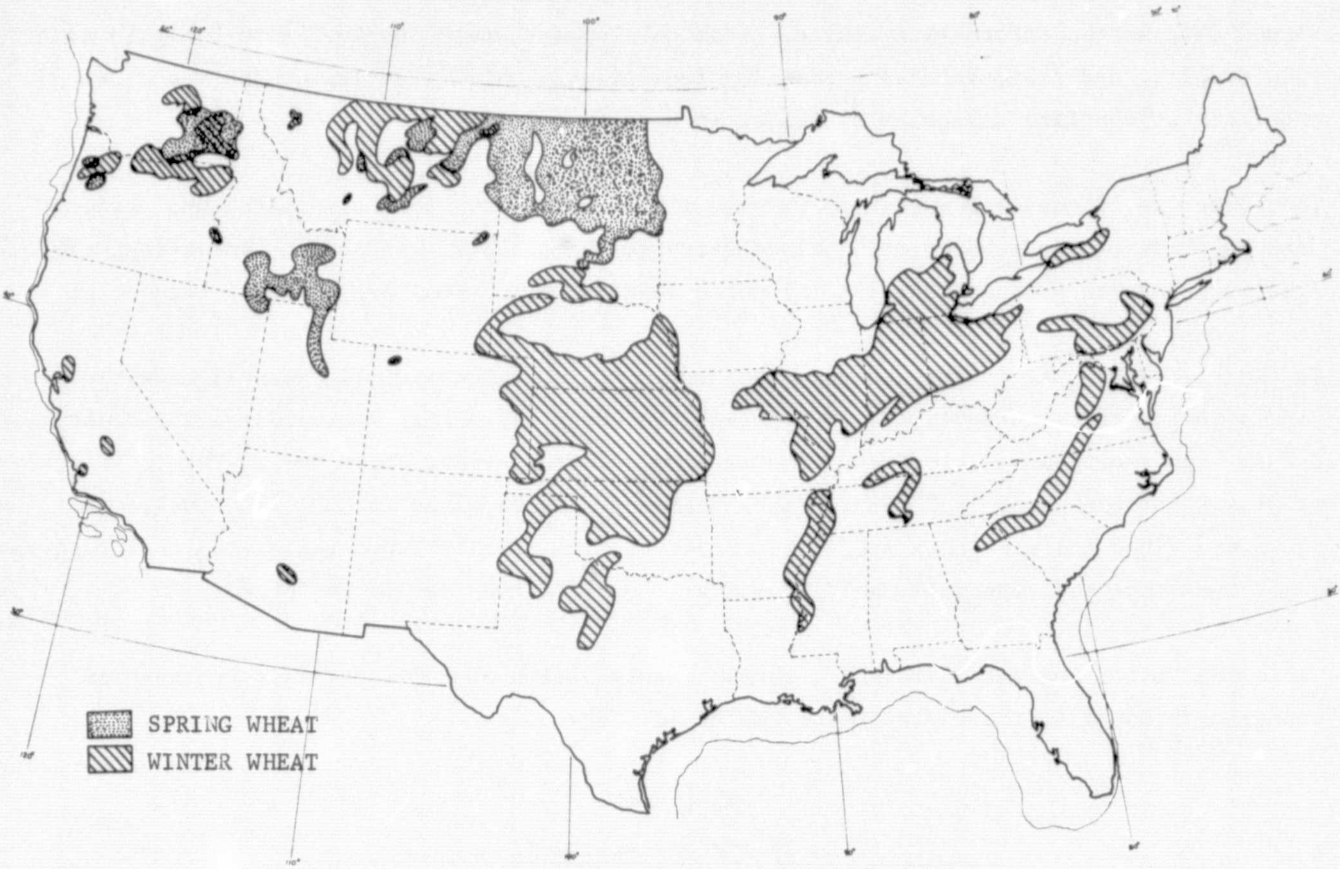

Figure 4-7. Major Wheat Cropping Areas (used for CIP samples)

990,000 pixels per band. For the 30-meter IFOV, each request will be composed of 300 lines with 367 pixels per line for a total of 110,100 pixels per band. Table 4-5 summarizes this data.

Table 4-5
CIP Segments
9 km High by 11 km Wide

IFOV	Number of Lines	Pixels Per Line	Total Number of Pixels per Segment
10	900	1100	990,000
30	300	367	110,100

A single analysis facility, located in Washington, D.C., was assumed for the CIP user. Timeliness of seven days and two days was assumed. As this study was purposely limited to the United States territory, no effort was made to estimate data volumes for foreign territories. The CIP demand is, thus, understated.

Forest Service: Recent legislation such as the Humphrey/Rarick Bill has established a Forest Service responsibility to inventory all forest lands over a 10-year cycle; the next

inventory will be due in 1979. While the Forest Service will likely use remotely sensed data for forest inventories, a timeliness requirement may not evolve. A one-month turn-around time may be sufficient for this application. Infestation detection could be an application that demands timely data delivery. However, some arguments have been advanced that infestation detection from satellites is not particularly useful as the areas must be large for detection, that is, detection is too late, infestation is already known, and the mortality is irreversible. On the other hand, advocates of this application stress timely data delivery of a few days.

Typically, three spectral bands is adequate for forest classification as diminishing returns set in for increased numbers of bands. However, different sets of three bands are required, depending on the forest type; thus, a general demand of six bands was assumed.

The assumed demands for this agency represent a compromise. Figure 4-8 indicates general areas of National Forests. These areas, when overlaid by satellite passes, were used to generate area estimates. This procedure ignores the Forest Service responsibility of inventorying private forest lands. On the other hand, timeliness of 7 days and 2 days was assumed.

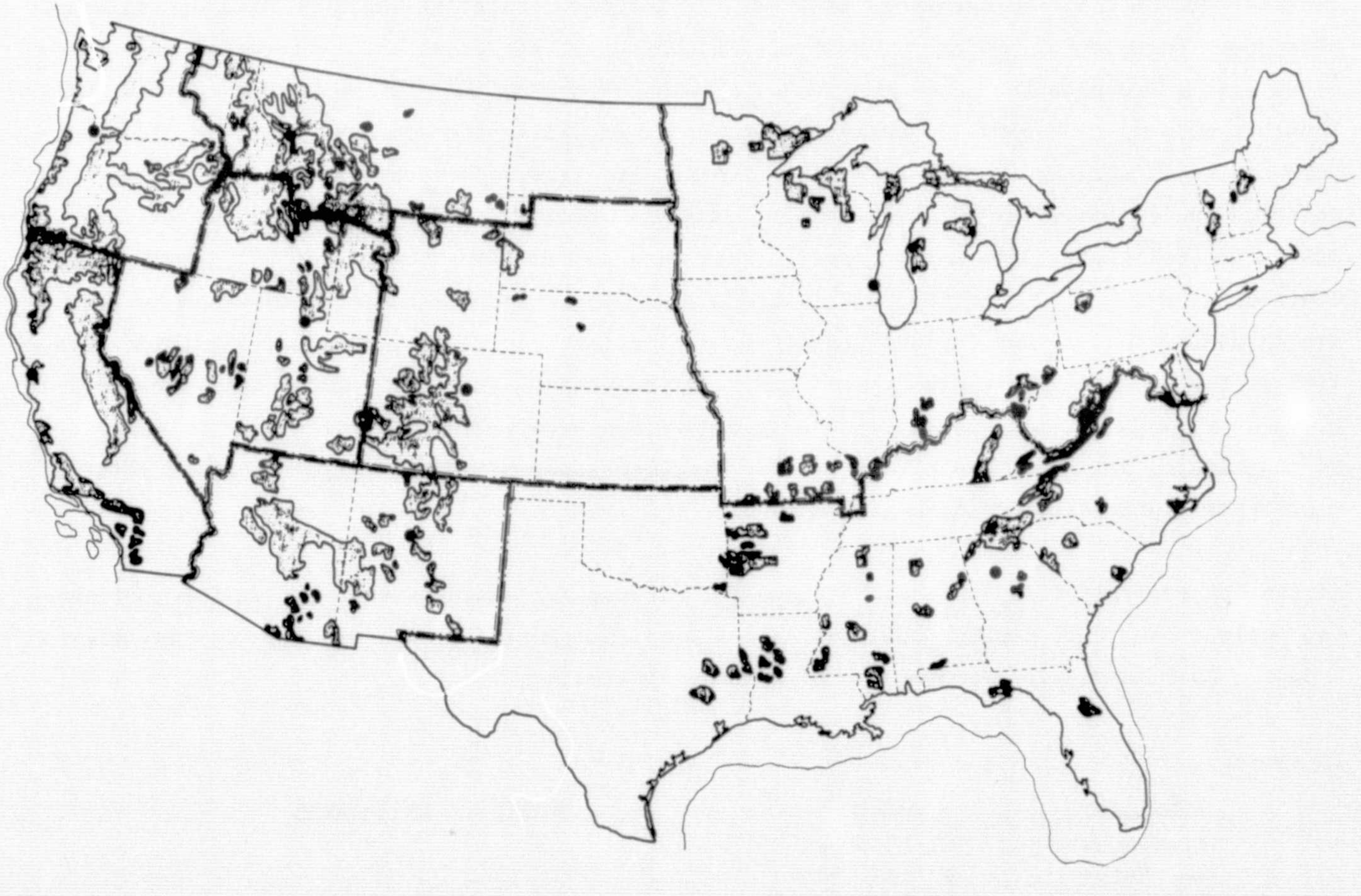

Figure 4-8. National Forests

Reception centers were assumed at Forest Service District offices with a cumulative total delivered to Washington. This potential demand is summarized as follows:

Location	Length	Bands	Timeliness
District Office	all national forest land	6	7
District Office	all national forest land	6	2
Washington	cumulative	6	7
Washington	cumulative	6	2

4.3.1.4 Environmental Protection Agency: The current EPA organization has three environmental research centers located at Las Vegas, Cincinnati, and Research Triangle Park, North Carolina. This latter facility is now oriented toward atmospheric pollution while the Cincinnati facility emphasizes treatment technology for water supplies, development of analysis methods, and test standardization. The Las Vegas facility is currently best equipped for remotely sensed data processing. Accordingly, this facility was designated in this model as the reception center for data.

Data demands by the Environmental Protection Agency are difficult to predict. The current official position of the Agency is that the resolution of satellite-derived data is inadequate to support enforcement policies. However, EPA personnel are using satellite data, an example being lake eutrophication classification [13]. An extension of this application would include land-use mapping to support assessment of nutrient and pollution sources. This application, however, would not require timely data delivery. If higher resolution data and improved coverage cycles prove useful for detecting some site-specific pollution sources, then an EPA demand for timely data might result. This data set would be similar to USACE inland-water monitoring, and BLM OCS Office coastal-water monitoring. Another application would be strip-mining monitoring. Given the uncertainty in projecting this demand, a relatively large area (50% of the land area on a given pass) and relatively small area (10% of the land area on a given pass) were assumed. A timeliness of 5 days was associated with these area estimates. In addition, a 50% land area with a two-day timeliness was assumed. This latter estimate represents a potentially substantial demand.

As the EPA responsibility extends over coastal waters, two demands were modeled for continental-shelf areas; full continental shelf and 20% of the continental shelf, both deliverable in 5 days. Four bands were assumed for this water application.

In summary,

Location	Length	Bands	Timeliness
Las Vegas	50% land area	6	5
Las Vegas	10% land area	6	2
Las Vegas	50% land area	6	2
Las Vegas	continental shelf area	4	5
Las Vegas	20% continental shelf area	4	5

4.3.1.5 Tennessee Valley Authority: TVA is responsible for approximately 36 x 10^6 acres of which 18 x 10^6 acres are forest lands. Figure 4-9 indicates the area of TVA responsibility. Personnel with the TVA have used remotely sensed data to develop land-cover maps [14]. Such studies, to date, have been on a small scale and the use of this data has not become an accepted tool by TVA management. However, the potential use exists for such applications as forest inventory and infestation, macroscale water quality, sulphur-dioxide contamination, and environmental-impact studies for power-line location. Each of the above could require rapid data delivery. For example, environmental-impact studies are typically performed within two-week deadlines and, thus, supporting data would be required within a few days.

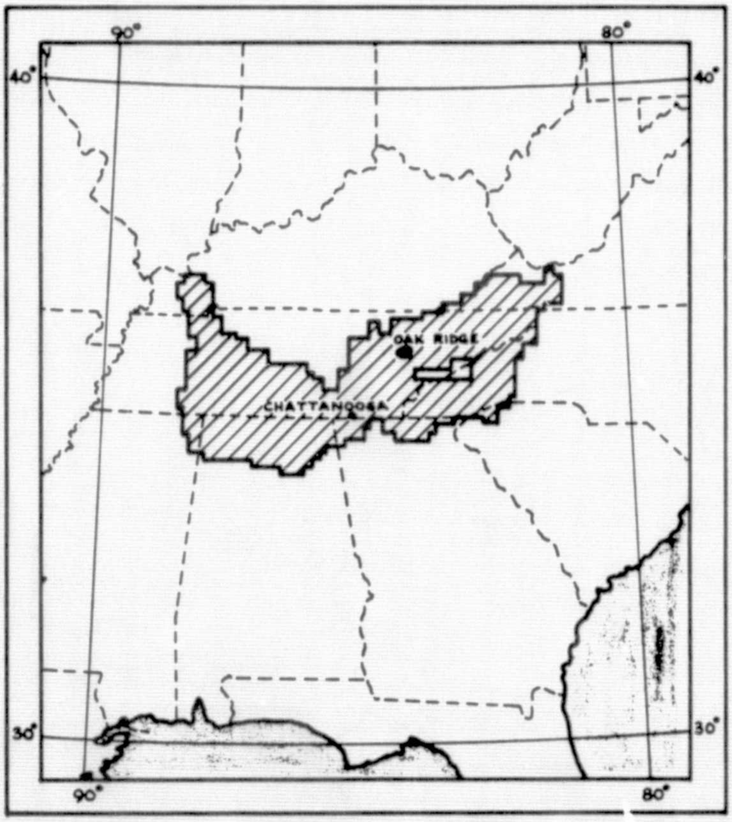

Figure 4-9 Tennessee Valley Authority

In order to estimate these potential demands, the following was assumed:

Location	Length	Bands	Timeliness
Chattanooga	entire TVA land	6	9
Chattanooga	entire TVA land	6	5
Chattanooga	25% of TVA land	6	2

4.3.1.6 U. S. Army Corps of Engineers: The USACE is organized into three Divisions: Civil Works, Facilities, and Military Construction. Responsiblity of the Civil Works Division extends virtually over all inland waters. The 1899 Act established Corps responsibilities for all discharges and structures on navigable waters. Section 404 and related court decisions have extended that responsibility to the headwaters (with flow rates of 5 cubic feet/sec) of all navigable waters including marshes and estuaries. Since Corps responsibility includes any structure or operation, such as dredging, change-detection monitoring with satellite-derived data could become a firm requirement. Coverage frequency would be biased toward urban areas; typically, once a month to semi-annually for rural areas. Since enforcement and, thus, field inspection may result from data analysis, a rapid data delivery is desirable. In addition to data requirements associated with inland water surveillance, the Corps could require data for river flow estimates and emergency assessment. The Civil Works Division is organized into 38 District Offices as shown in Figure 4-10. Each of these offices is relatively autonomous; thus, each location was modeled as a reception and processing center. Analysis requirements at the various districts should differ depending, for example, on whether they embrace coastal waters, large rivers and estuaries, or inland waters in arid regions. A standard 6-band demand was assumed. In addition, each entire district area was provided in either five days or one day. In addition, a small area demand of 10% of each district area required in one day was modeled.

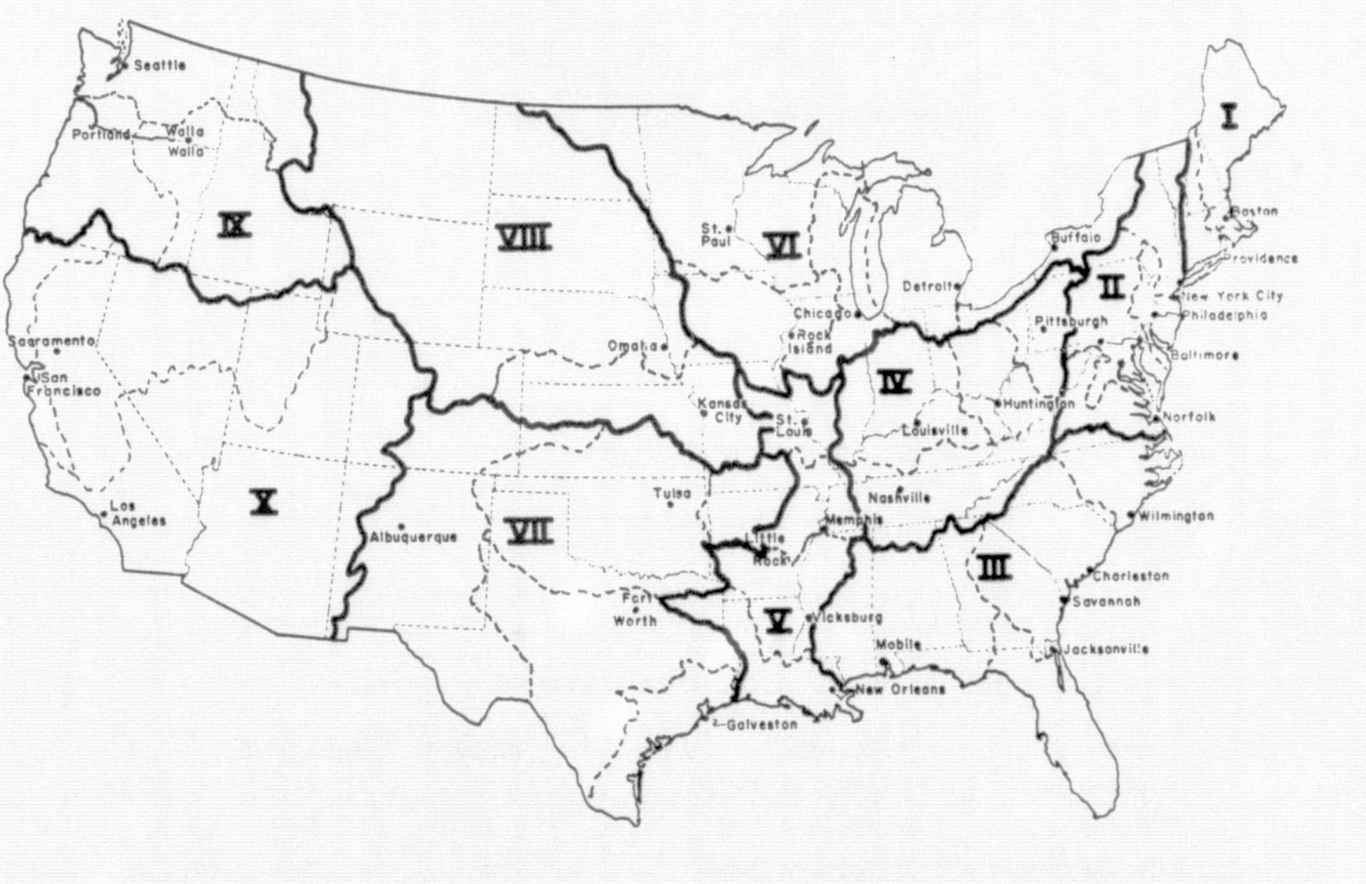

Figure 4-10. Area Locations for U.S. Army Corp of Engineers

In summary,

Location	Length	Bands	Timeliness
District Office	all district land	6	5
District Office	all district land	6	1
District Office	10% of district land	6	1

No demand was modeled for the Military Construction and Facilities Divisions of the Corps. While personnel in these divisions are actively evaluating the potential of remotely sensed data, no specific requirement for time-dependent data could be identified. If used, satellite-derived data will not be time sensitive but rather restricted to land-management applications involving, at best, an annual update. While increased resolution should increase potential uses, no application requiring data delivery in less than 30 days has been identified for these divisions.

4.3.1.6 Department of Transportation: During peacetime, the Coast Guard is within the Department of Transportation. One functional responsibility of the Coast Guard is to monitor shipping hazards, such as ice, in coastal waters. Although visible and infrared imagery will provide this data in cloud-free areas, the primary interest within the Coast Guard is toward microwave sensors, such as carried on SeaSat, that will penetrate some cloud cover. However, a potential demand of one scene and/or one-half scene per swath was estimated for earth-resources data. A timeliness of one day was assumed for this data.

4.3.2 State Government: The state demand will be varied individually and will collectively encompass most, if not all, applications for remotely sensed data. In addition, the programs will involve many cooperative ventures with federal agencies. As an example, state agencies in California and Oregon are participating with the Corps of Engineers, NASA, Bonneville Power Administration, and the Geological Survey to evaluate the utility of satellite data as an input to river-flow prediction.

Furthermore, the state agencies are highly sensitive to cost. As the utility of the data increases with improved resolution, so will the cost of data processing. Different states will respond to this tradeoff differently. A point frequently stated is the need for resolution to the proprietary unit. If this resolution were available, then many expenses associated with property transactions would be offset by availability of such data. However, resolution to this scale will be difficult to obtain. Ten-meter data might provide this capability.

In the course of developing this model, numerous interviews were held with individuals involved in state use of LANDSAT, Skylab, and aircraft data. The response was highly varied, ranging from skepticism to optimistic acceptance. Given the current status of government financing, it would be unrealistic to assume that a substantial number of states will accept

the costs of communication links (receive only) and data processing. Any accurate prediction of state demand must be based on an intimate evaluation of each state's priorities and a prediction of the future federal/state relative responsibilities. As this model is parametric, such a prediction is not necessary. Thus a 'standard demand' was modeled for each state.

Interstate cooperation, either as a compact Regional Commission or the simple exchange of information, is increasing. Thus, cooperative regional reception, processing, and archival centers can be expected to develop. Typically, these should tend to develop along existing areas of cooperation as, for instance, the Ohio, Kentucky, and Indiana (OKI) Regional Commission or the Susquehanna River Basin. However, federal influence will also pace this regional orientation, if any. In order to model potential regional locations, the standard federal regions as shown in Figure 4-11 were used. Thus, the model of state demand allows for any state or group of states or region to exert a demand. Each and any state or region can be included or excluded to tailor the potential demand.

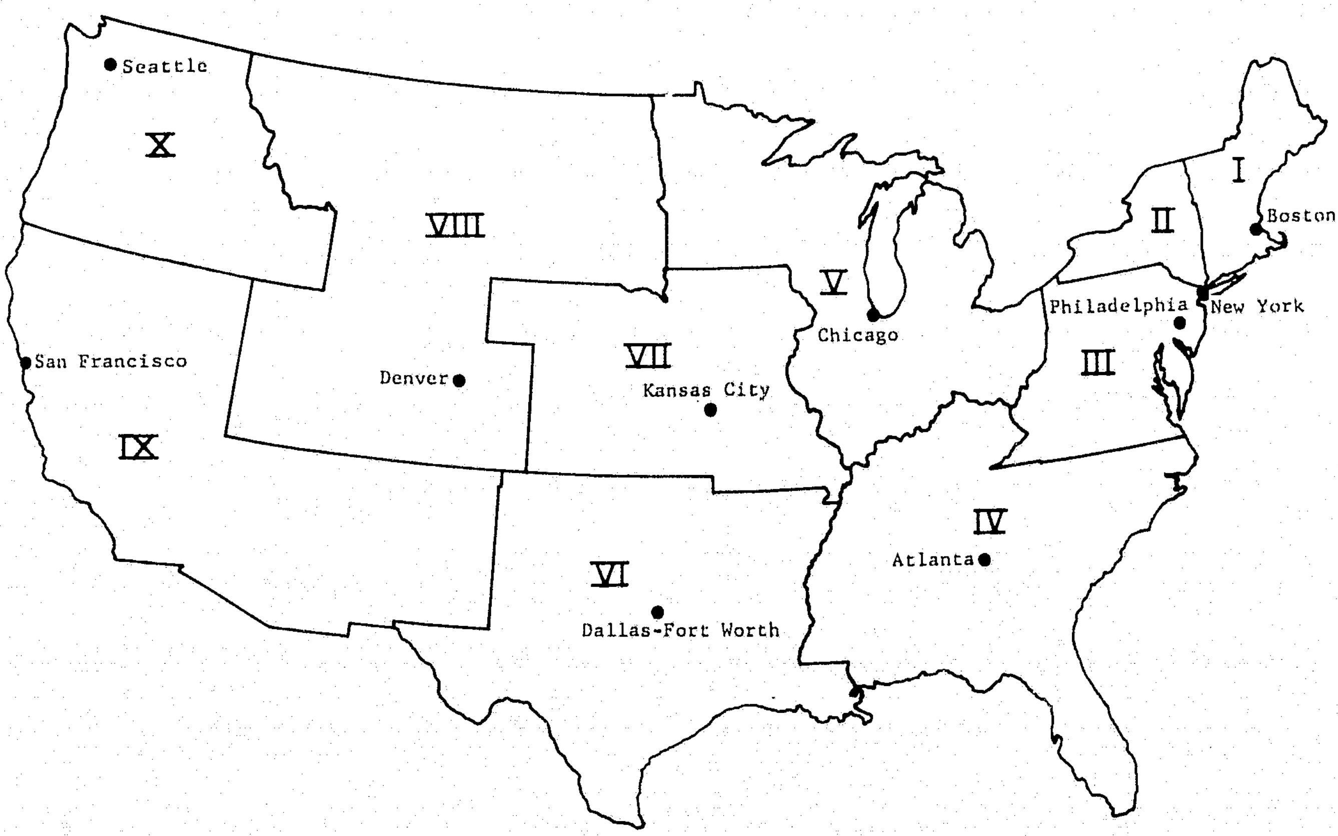

Figure 4-11. Standard Federal Regions

The one requirement for timely data that was uniformly cited by persons in state agencies was emergency damage assessment. Numerous applications for this data were specified. For example, in the case of flood plain analysis, data would be useful for evacuation planning, preparation of application for disaster designation, and shift in cropping practices at the

farm level [15] (change in crop types based on expected flood retreat). Shifts in crop types then impact the transportation and fertilizer industries in determining the type and amount of vehicles required. In the event of a major disaster, numerous agencies become involved such as the National Guard, Corps of Engineers, and Red Cross. Typically, a state Civil Defense agency coordinates activities and data dissemination would flow through such an agency.

The states manage timber land from which one billion board feet of timber are cut annually, bringing a net income to these states of $72 million [16]. Over 630 million acres are protected by state forestry agencies. The Forest Service cooperates with state agencies by virtue of the Clarke-McNary Act of 1924 and, thus, cooperative reception and processing is possible. Timber mensuration, infestation monitoring, and burn assessment are potential uses for forest data. Mensuration does not require timely data dissemination and, generally, could be achieved with the land-use data set. Burn assessment data can set into motion various actions (some depending on the season) such as reforestration or erosion control. Timely receipt of such data is desired. Similarly, effective insect control, if effected by satellite-derived data, requires a rapid data availability, a factor which now precludes this use from operational status.

Water quality assessment and coastal-zone management represent uncertain areas of potential timely demand. The majority consensus among state users was that neither application would require data delivery in less than two weeks after observation; in most cases, months would be sufficient. Some instances of water pollution represent a threat to public health; one example being ingestion of asbestos fibers by Chicago pumping stations, the source ultimately traced to industrial activity. In this case, the specific pollution was observed on both satellite and aircraft imagery. Furthermore, if enforcement decisions associated with water pollution are initiated by macroscale observations such as satellite data, then a timely data delivery is required. However, the use of satellite data to support pollution enforcement is a point of controversy among potential users. The primary contention rests on the resolution necessary to identify site-specific pollution sources. It may be assumed that improved resolution to 30m or even 10m would tend to increase the demand for this type of application. Agricultural pollution abatement is a primary concern of many states and represents a potentially large coverage area.

Coastal-zone management involves dynamic processes, such as shoreline erosion, that may impose reasonably rapid data dissemination. However, in one case [17] it was felt that data delivery in two weeks or less would be required only after a major storm event which occurs on a frequency in the order of one per decade. The consensus was that time requirements on coastal-water data would not be severe.

Several demands for timely data delivery associated with agricultural applications could develop in some states. If crop infestation detection from satellites were feasibly demonstrated, then a rapid data delivery of large-area coverage could result. Currently, most state agricultural agencies work in cooperation with USDA agencies depending on the latter for crop mensuration. Some feel that the statistics at the state level can be improved. The availability of timely data and state or regional processing facilities could result in more independent state efforts to assess crop types and areas. This application, which would result in large amounts of timely required data, is difficult to predict. In this instance, the major technological difficulty of signature extension represents an uncertainty in future utility.

Other applications requiring timely delivery of remotely sensed data were identified. One example was sulphur-dioxide air pollution in Illinois that apparently resulted in detectable crop damage in Kentucky. Though this event occurred in July 1975, data was not available by October [18]. Another example is frost damage assessment that would be useful to state agricultural agencies. Range data would support forage estimates and, thus, recommended grazing densities. During dry months, this data can become urgent. Use of satellite data to monitor strip-mining and associated reclamation efforts has been successfully demonstrated [19] and has a relatively rapid timeliness requirement associated with enforcement. The monitoring of development projects, particularly in erosion-prone areas, also exhibits a timely demand.

The predominant state use of remotely sensed data is for land-use mapping. This application will, no doubt, be accentuated as land-use legislation becomes law in various states. The need for a uniform data base to initiate planning was frequently cited. However, by the time that higher resolution satellite data becomes available, many states will have completed the intital land-use maps. Satellite data will thus evolve into a change-detection role in which it will be used as a mensuration overview to support field inspection. While this data involves total state coverage, quick turn-arounds are not required.

There will be substantial variation in data demand from region to region. For example, the dry southwestern region will tend toward water mensuration, particularly in the summer months, whereas regions of storm-driven coast lines, as in the Gulf or Atlantic, will tend toward coastal-zone data, particularly after the passage of storms. Frequency of update, timeliness, and spectral band preference will vary. In order to avoid this impressive problem, a relatively standard product demand was assumed for each regional and state center. Specific applications were deleted for some centers while the others were sized for each state or region.

The general data demand assumed was:

Location	Length	Bands	Timeliness
State Capitol	all state land	7	5
State Capitol	50% state land	7	5
State Capitol	10% state land	7	5
State Capitol	10% state land	7	2
State Capitol	agricultural land	7	2

This set of potential demands allows a range from a relatively large data volume to a small data volume, both with a modest timeliness of 5 days. In addition, two timely requirements (10% of all land and agricultural land) was included. The agricultural demand for each swath was estimated by using the ratio to the total path length over each state (or region).

4.3.3 Regional Commissions: There are several hundred regional commissions in the United States; some created by federal law and others established by compact agreements between states. Examples of the former are the six River Basin Commissions and the eight Regional Action Planning Commissions both listed below:

River Basins	Regional Action Planning Commissions
Upper MIssissippi	Appalachian
Pacific Northwest	New England
Ohio River	Coastal Plains
New England	Ozarks
Missouri River	Upper Great Lakes
Great Lakes	Old West
	Four Corners
	Pacific Northwest

An interstate compact is a legal agreement combining the attributes of state statutes and a contract. There are over 200 such regional commissions in the United States.

Numerous individuals in regional commissions have used or have evaluated the potential of remotely sensed data in their endeavors. The current resolution and registration has dampened the enthusiasm of some. Others, such as the Pacific Northwest Regional Commission and the OKI regional Council of Governments [20], have successfully used LANDSAT data. Most regional commissions operate in a long-term planning context with limited, if any, enforcement authority. Thus, a timely data demand is not likely. However, in view of the large number of potential regional commission users, a one-scene (100 n.mi.) and a two-scene (200 n.mi.) demand were modeled with five-day timeliness for both demands and a two-day timeliness for the 200-n.mi. demand. Six bands were assumed for these demands.

4.3.4 Private Sector: Table 4-2 in Section 4.1.1 indicates that the private sector represents the largest demand for products from the EROS Data Center. The same paper [21] from which this table was excerpted listed major U. S. industry users as:

Gulf Oil Co	Dames and Moore
Bechtel Inc.	Chevron
Atlantic Richfield Co.	Continental Oil Co.
Union Carbide	AVCO Systems
Mobile Oil	Earthsat Co.
Texaco Inc.	General Electric Co.

By inspection, it can be seen that most of these firms are associated with mineral extraction. As will be noted subsequently, it is doubtful that the mineral industry will require rapid data delivery.

Two types of private centers are possible. First, commercial firms that derive income from the the sale of analysis products and, second, firms that use the data directly. In the former case, the quantity of products sold must provide sufficient income to offset the expense of a reception and processing facility. Thus, a high data demand is necessary to support their existence. In addition, competition in the market place will accentuate the timeliness demand. To bound this demand, the following commercial demand was assumed:

1. 10% of land area per pass within 5 days
2. 10% of land area per pass within 1 day
3. 25% of land area per pass within 5 days
4. 25% of land area per pass within 1 day

Again, this demand can be tailored on a per-pass basis by including any one of the above demands. Five commercial centers were assumed located in Boston, Washington, Lafayette, Houston, and Berkeley. Seven-band demand was assumed.

Industries that are candidates for reception and processing of satellite-derived data for internal use are mineral, paper and wood, and agriculture.

Potential private agricultural users fall into two categories: firms associated with international trade and firms with large land holdings directly involved in farm production.

While large agricultural concerns in international trade are potential 'on-line' users, their demand, if any, will be determined largely by the availability of government data particularly relative to international crops. Current USDA SRS crop estimates are probably sufficiently accurate for the U.S. crop. Thus, there would be little incentive for private concerns to assume the expense of reception and processing for U.S. data alone. As the

availability of international data such as the CIP applications is unlikely, there appears that no demand will develop in this sector for this data.

Similarly, it is doubtful that corporate or large-area farms would assume the cost of direct reception. Potential use by large agricultural firms include an early inventory of acres planted [22] and, if proven successful, detection of insect infestation. Nevertheless, it is unlikely that the farm owner or manager would gain significant information to substantiate the cost of direct reception. Therefore, no demand was modeled for this application.

The interest of mineral extraction companies is indicated by the EROS product sales cited previously. Typically, this data requirement which is primarily directed toward geological interpretation does not require rapid delivery nor frequent update. Thus, again, no demand was modeled for this sector.

Paper and wood industry concerns with large timber holdings are also candidates for 'on-line' reception. A necessary pre-requisite for use of this data is an existing forest inventory developed in a digital-data base. The demand in this industrial sector will be determined largely by the proven utility of 30m or 10m data in reducing field inspection costs. This tradeoff is difficult to predict. In order to estimate this demand, a one-scene (100 n.mi.) and two-scene (200 n.mi.) requirement was hypothesized for each pass.

4.3.5 Unspecified Users: Obviously, any attempt to predict user demand a decade hence will fail to recognize all potential users. In view of this difficulty, a set of unspecified users was modeled. This potential demand allows for one to fifteen scenes at either five-day or one-day timeliness to be incorporated on any satellite pass. Unspecified users were, thus, designated:

Location M	Length (n.mi.)	Bands	Timeliness (days)
Denver	100	7	4
Los Angeles	200	7	5
Atlanta	400	7	5
Washington	800	7	5
Washington	100	7	1
Atlanta	200	7	1
Los Angeles	400	7	1
Denver	800	7	1

SECTION 5.0

USER MODEL

5.1 Introduction.

The potential data demands appearing in the previous section and in Appendix C specify a probable demand based on potential users. Not all agencies and institutions would be likely to justify the expense of on-line operation, and, even so, the build-up would be gradual, paced by a growth in data dissemination capabilities. Thus, a simulation of all potential users would represent an overstatement of demand (particularly early demand) and, therefore, would be an unrealistic evaluation of technology requirements. Thus, two sets of user demands representing what might be considered a near-term demand and a more developed demand were selected. The use of both sets provides a means to evaluate the effect of demand on the network.

5.2 Nominal User Demand.

This demand is intended as a moderate estimate of cumulative demand. Therefore, both the number of users and the timeliness requirements are relaxed.

Federal demand is represented by 58 reception terminals. It is assumed that the Department of Agriculture receives all data over land on every pass within two days of observation for distribution within its own network. One reception center at Salt Lake City handles this data. Likewise, the Department of Interior receives all data within two days, including the continental-shelf water, for internal distribution from Sioux Falls. The BLM demand is represented by both state offices and outer-continental-shelf offices. In the case of the former, it was assumed that the total BLM areas were monitored every 30 days with a timeliness of delivery within 9 days. This would satisfy most BLM requirements as now projected. A sector monitoring mode was assumed for the OCS offices consisting of 20% of the continental shelf every 7 days delivered within 5 days of observation. In addition, the same data for both offices is provided to a central site in Washington, D. C.

Each Corps of Engineers receives data for each entire district area every 30 days within 5 days.

State-government demand was represented by four independent states (California, New York, Ohio and Texas) and by two regions of combined states; region IV (Atlanta), and region X (Seattle). For each of these, it was assumed that 50% of the total land area was surveyed twice a year with a timeliness of 5 days. In addition, 10% of the land area was monitored every two weeks, again with a 5-day delivery requirement. These two demands reflect a

general land-use classification and a more specific application such as strip-mining monitoring, pollution monitoring, or infestation detection.

Finally, regional commission demand, consisting of one scene every 60 days, was assumed for the 24th and 38th pass. No private or unspecified demand was assumed.

Table 5-1 lists these agencies and the specific demands related to the assumed coverage cycle and timeliness. Examples of swath-by-swath data for this demand are given in Appendix D.

Table 5-1

Nominal User Demand

Designation	User	Timeliness (days)	Coverage Cycle (days)	Probability* of Demand
101	USDA, Salt Lake City	2	Every Pass	1.0
180	USDA, (CIP), Washington	7	Every Pass	1.0
104	USDI, Sioux Falls	2	Every Pass	1.0
108 & 111	BLM, COS, 20% contintental shelf	5	7	0.5
112-129	BLM, State Offices, total area	9	30	0.333
132	BLM, Headqtrs., OCS cumulative	5	7	0.5
133	BLM, Headqtrs., State cumulative	9	30	0.333
144-171	USACE District Offices, total district	5	30	0.333
300-344	State Government (50% land)	5	180	0.05
	State Government (10% land)	5	14	0.5
345-364	State regions (50% land)	5	180	0.05
	State regions (10% land)	5	14	0.5
365	Regional Commission (100 n.m.)	5	60	0.153

*For 2 satellites, 18-day repeat cycle.

As noted in the foregoing discussion, user demand was developed from institutional jurisdiction. That is, the area of each demand is determined by institutional boundaries. The data volume is then determined by this area, the spatial resolution, and the number of requested bands. Figures 5-1 and 5-2 are histograms indicating the data volume in terms of number of requests for 30m and 10m data. These histograms represent the maximum network loading that would result if every assumed user requested data in a given 9-day cycle. In this model, the average volume per request is 7.65 gigabits for 30m data and 97.73 gigabits for 10m data. These represent 2.6 scenes and 2.2 scenes, respectively.

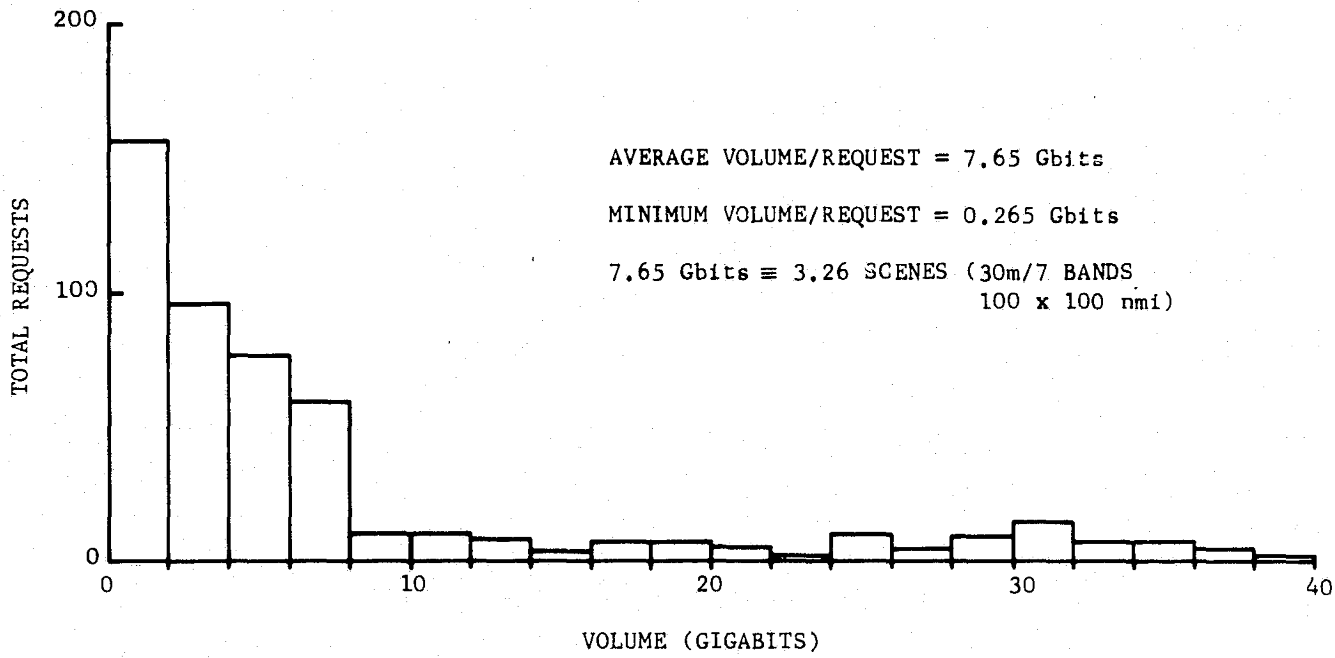

Figure 5-1. Number of Requests by Data Volume Nominal Demand, 30m/7 Bands-
Total Requests = 505.

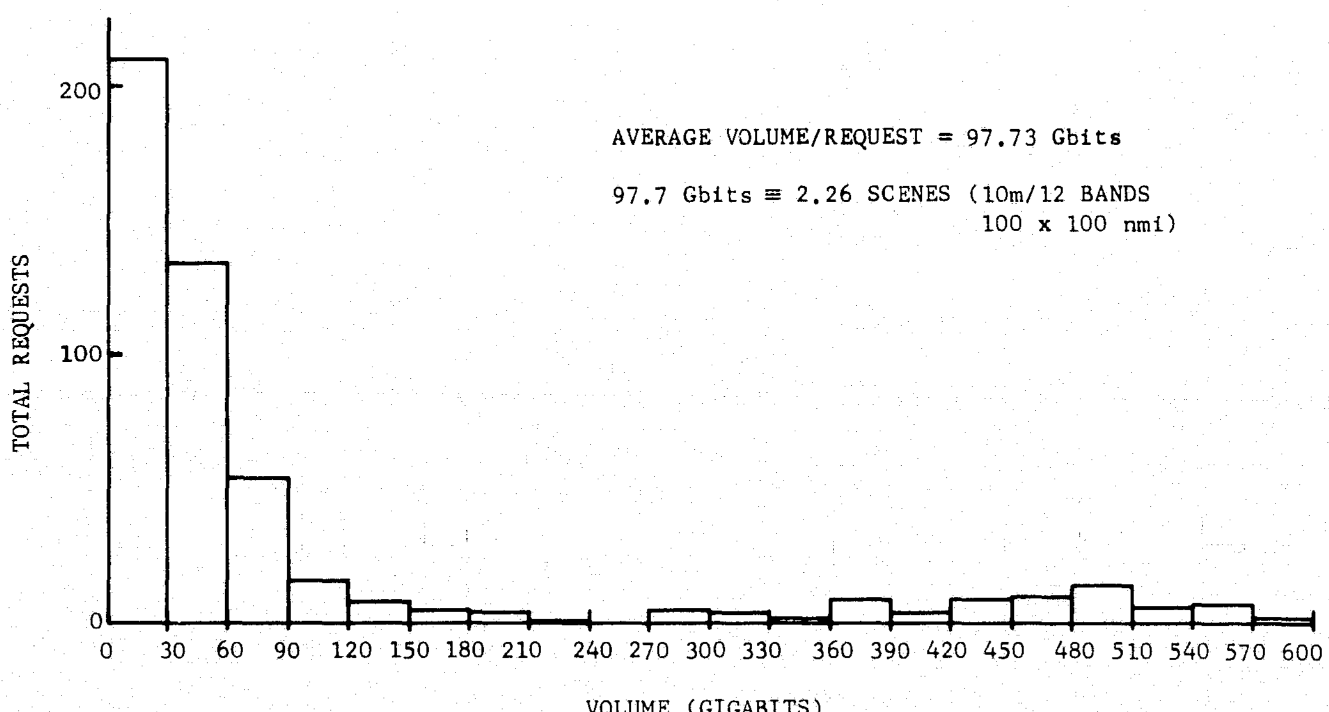

Figure 5-2. Number of Requests by Data Volume Nominal Demand, 10m/12 Bands-
Total Requests = 505.

5.3 Expanded Demand

The purpose of this demand estimate is to stress the dissemination network and investigate required technologies to support a growing demand. Accordingly, the minimum timeliness was assumed for each selected user.

Federal demand is represented by 73 reception centers. This demand is dominated by the USDA Salt Lake City and USDI Sioux Falls centers that require virtually all data within 24 hours. Additional federal agencies over the nominal demand are: Bureau of Indian Affairs, Forest Service, Environmental Protection Agency, and the Tennessee Valley Authority.

The timeliness for some nominal federal users was decreased; for the CIP demand from 7 days to 2 days, and for the OCS office from 5 days to 2 days. BLM state office demand of 10% of the area every 14 days delivered within 2 days was added. This represents the application of supporting forage estimates. Likewise, a 10%-of-district area monitored every 7 days with one-day timeliness was added to the USACE nominal demand while the coverage cycle for the total-district area demand was increased from 30 days to 120 days.

The added federal demands consisted of the Forest Service monitoring National Forests every 30 days with a 2-day timeliness, the Bureau of Indian Affairs monitoring reservation lands every 60 days with a 2-day timeliness, and the monitoring of all TVA land every 180 days with a 5-day timeliness. In addition, the EPA demand reflects 50% of all land area monitored every 60 days with 2-day timeliness, 10% of all land area monitored every 7 days but with 5-day timeliness, and 20% of continental shelf monitored every 14 days. The EPA demand indicates a substantial use of satellite-derived data by that agency.

State demand was estimated but assumed that all CONUS states would participate through ten regional centers. In this case, 50% of all land area is monitored every 180 days with 5-day timeliness. In addition, agricultural lands are monitored every 14 days with 2-day timeliness.

Regional commission demand was estimated by two scenes on every third orbit delivered in 2 days. The private sector was estimated by a 'commercial' demand of 10% of all land area and, in addition, three scenes were assumed for each pass for unspecified users. One-day timeliness was assumed for both classes of users. Swath-by-swath data indicating these demands is given in Appendix D. Table 5-2 presents the assumptions associated with the expanded demand.

The volume demands indicated by this model are depicted in Figures 5-3 and 5-4 for 30m/7-band and 10m/12-band data, respectively. The average data volume per request was 5.829 gigabits (30m) and 67.78 gigabits (10m). There are 1142 possible requests over 9 days.

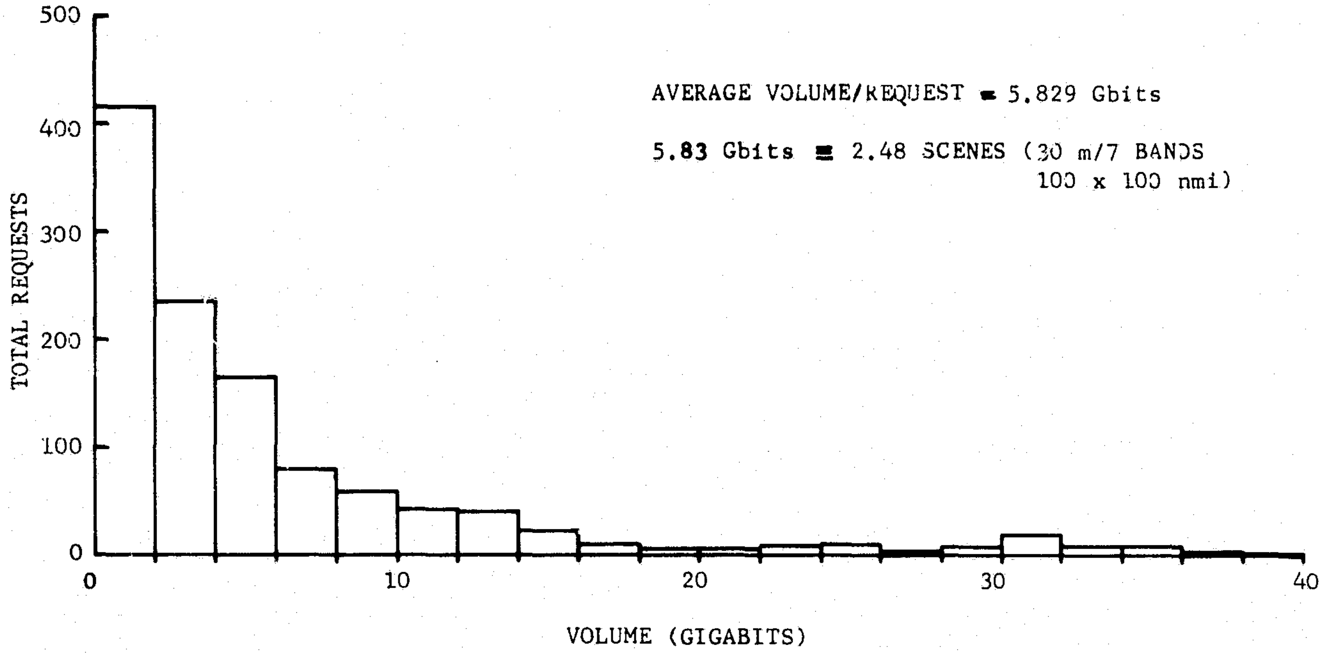

Figure 5-3. Expanded Case, 30m/7 Bands - Total Requests = 1142.

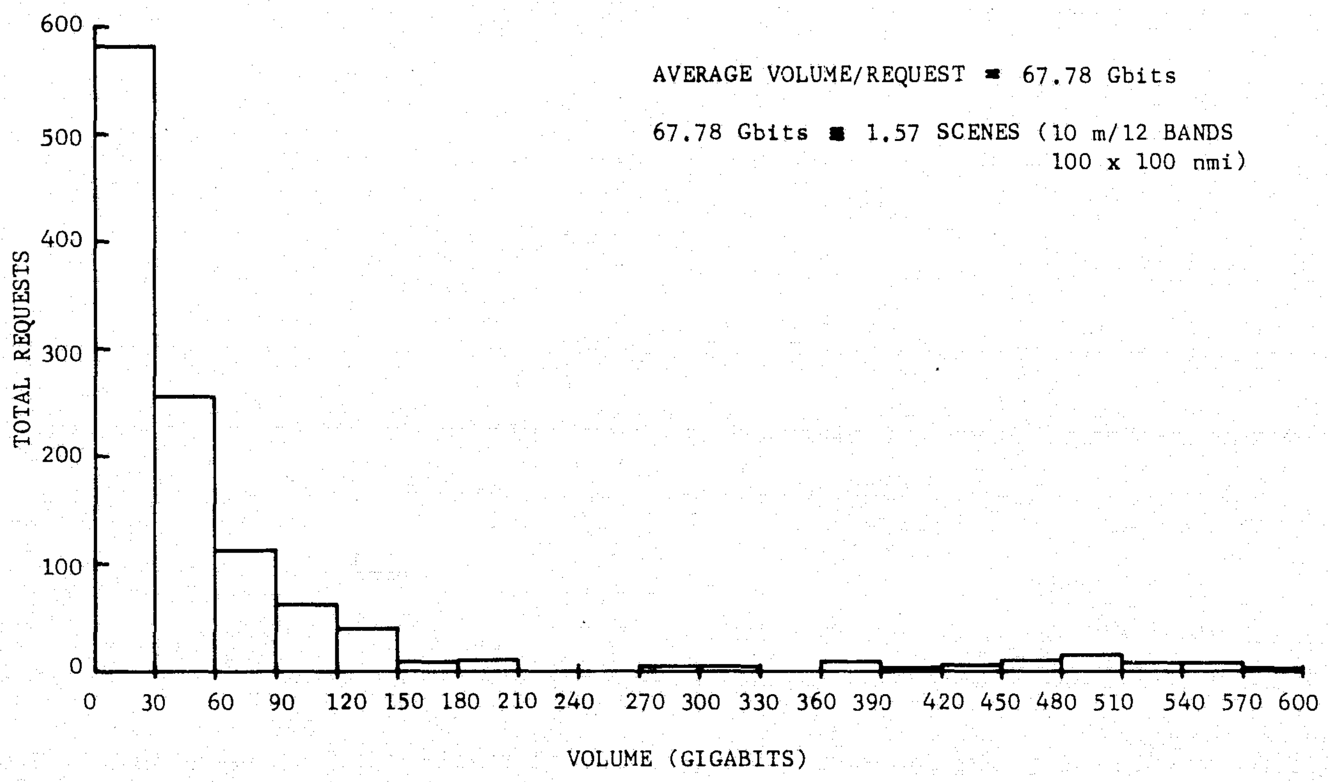

Figure 5-4. Maximum Case, 10m/12 Bands - Total Requests = 1142.

Table 5-2

Expanded User Demand

Designation	User	Timeliness (days)	Coverage Cycle (days)	Probability of Demand*
100	USDA, Salt Lake City	1	Every Pass	1.0
181	USDA, (CIP), Washington	2	Every Pass	1.0
103	USDI, Sioux Falls	1	Every Pass	1.0
183-191	USDA, Forest Service District Offices (National Forests)	2	30	0.333
107 and 110	BLM OCS Offices (all area)	2	30	0.333
112-129	BLM, State Offices (all area)	9	60	0.152
	BLM, State Offices (10% area)	2	14	0.5
174-179	BIA, District Offices (all reservation area)	2	60	0.152
136	EPA, Las Vegas (10% land)	5	7	0.5
138	EPA, Las Vegas (50% land)	2	60	0.152
140	EPA, Las Vegas (20% continental shelf)	5	14	0.5
193	TVA, Chattanooga, all area	5	180	0.005
144-173	USACE, District Offices, all area	5	120	0.061
	USACE, District Offices, 10% area	1	7	0.5
345-364	State regions, 50% land	5	180	0.05
	State regions, agriculture lands	2	14	0.5
367	Regional Commissions	2	180	0.05
401	Commercial	1	14	0.5
504	Unspecified	1	14	0.5
505	Unspecified	1	14	0.5

*For 2 satellites, 18-day repeat cycle.

The nominal and expanded user model demand can be more properly summarized by determining the probable number of requests per coverage cycle and the probable volume per request per coverage cycle. This was done in the following manner.

The probable number of requests per coverage cycle, N_R, is obtained by summing the probabilities of demand associated with each request, or,

$$\overline{N}_R = \sum_j \sum_i p_{i_j}$$

where p_{i_j} = probability of demand for user i of swath j.

The probable total volume per coverage cycle, $\overline{V}_c$, is given by,

$$\overline{V}_c = \sum_j \sum_i p_{ij} V_{ij}$$

where

V_{ij} = volume of data requested by user i of swath j.

Finally, the probable volume per request per coverage cycle, $\overline{V}_R$, is given by

$$V_R = \frac{V_c}{\overline{N}_R} = \frac{\sum_j \sum_i p_{ij} V_{ij}}{\sum_j \sum_i p_{ij}}$$

The results for CONUS coverage for both the 30m and 10m cases and for both nominal and expanded demand is given in Table 5-3.

Table 5-3

Probable Demand Volumes

- CONUS (Lower 48 States) -

	Probable No. of Requests/ Coverage Cycle		Probable Volume/Request/ Coverage Cycle, Gigabits	
	30/7	10/12	30/7	10/12
Nominal Case	225	225	14.3	203.8
Expanded Case	419	419	9.1	122.5

As stated earlier, rapid timeliness was emphasized in the expanded model. This is indicated in Figure 5-5 which is a histogram indicating the number of requests by timeliness for both the nominal and the expanded model. By inspection, the bulk of the added demand in the expanded case is associated with 1- or 2-day timeliness.

5.4 Alaska.

Due to the geographical separation and the potentially large data volume, Alaska demand was treated separately. This allows simulations to be performed with and without the Alaska impact. The Alaskan continental shelf covers an area as large as the entire CONUS continental shelf. If mining activities become generalized over this area, and, if a surveillance mode is proven desirable, then large data volumes could be generated. In order to assess the impact of this application, the entire continental shelf was used in developing this demand.

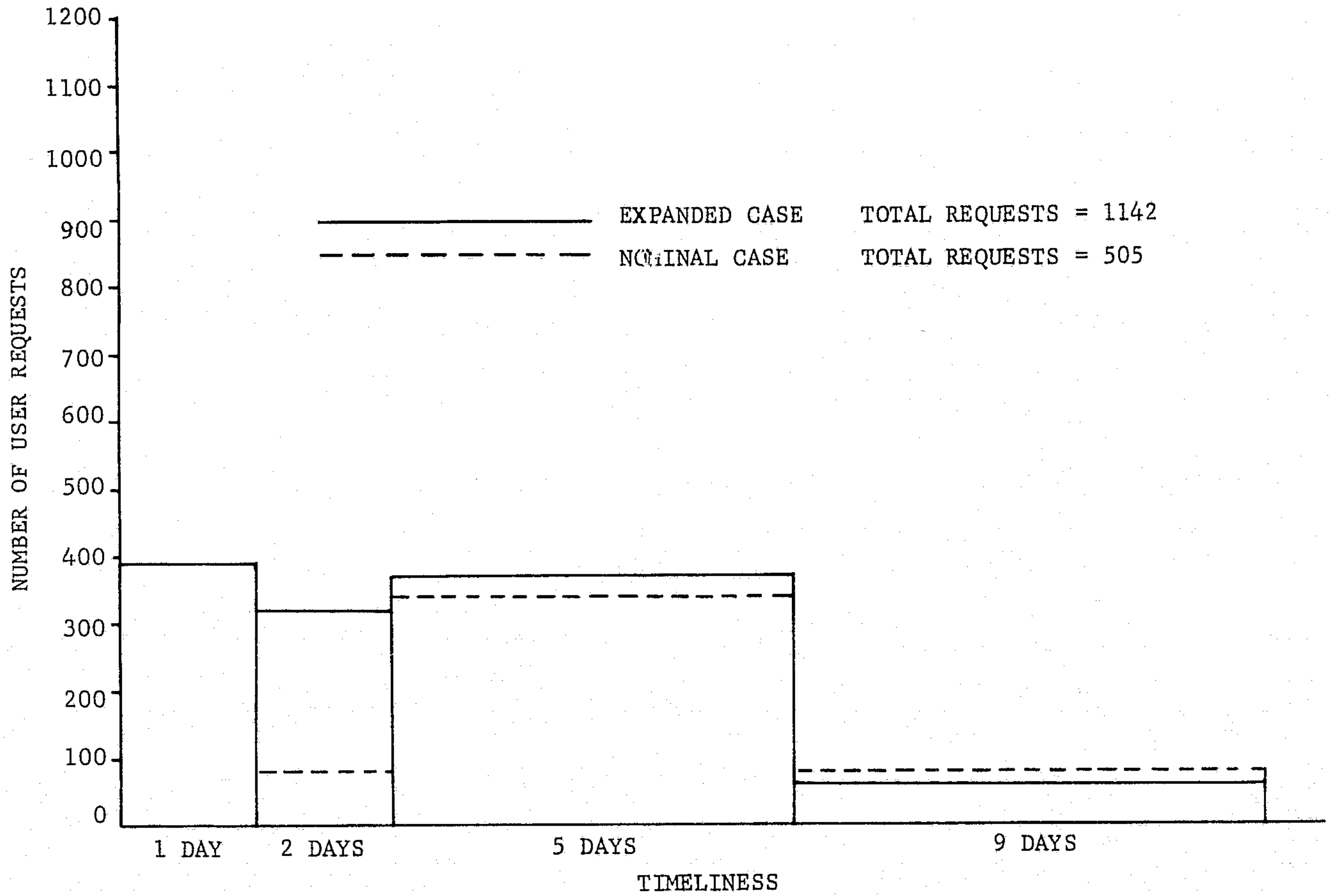

Figure 5-5. Timeliness Requirements Distribution

The large data demands associated with the Departments of Agriculture and Interior (EROS) were deleted from this model for Alaska. This was done as Alaskan agricultural lands represent less than 0.5% of total area and the BLM responsibility covers over 80% of the land area. Direct transmission to both the BLM and EROS seems grossly redundant as both agencies are within the same department.

As with potential CONUS users, the Alaskan demand was selected for both nominal and expanded cases. These are described in the following sections.

5.4.1 Nominal Alaskan Demand: The nominal demand was tailored for three federal agencies (Corps of Engineers and the BLM state and OCS offices), the State of Alaska, and two unspecified demands. While this represents a small number of users, the total data volume is substantial. This situation leads to consideration of a single reception center in Alaska capable of all data preprocessing. If timely data demands do not develop for Alaskan data by continental United States users, then data trunking costs could be eliminated at the expense of an additional preprocessing facility.

For the BLM, it was assumed that all BLM land area would be monitored every 30 days with a timeliness of 9 days. For the OCS office it was assumed that 20% of the continental shelf would be monitored every 7 days with a 5-day timeliness.

The Corps of Engineers demand assumed that the entire district (all land area) would be monitored every 30 days with a timeliness of 5 days.

The State of Alaska demand is identical to the nominal demand of CONUS states; namely, 50% and 10% of land area monitored in 180 and 14 days, respectively, and delivered in 5 days.

Unspecified user demand was assumed as three scenes per pass monitored every 14 days and delivered in 5 days.

These demands, taken together, reflect considerable redundancy strongly implying the efficiency of a single reception center for Alaska.

Examples of swath-by-swath data for this demand appear in Appendix D. Table 5-4 indicates the assumed demands by agency.

Table 5-4

Nominal Alaska User Demand

Designation	User	Timeliness (days)	Coverage Cycle (days)	Probability of Demand
108	BLM, OSC, 20% continental shelf	5	7	0.5
112	BLM, State Office, all land	9	30	0.333
144	USACE, Total District	5	30	0.333
301	State Government, 50% land	5	180	0.05
302	State Government, 10% land	5	14	0.5
500	Unspecified, 1 scene	5	14	0.5
502	Unspecified, 2 scenes	5	14	0.5

5.4.2 Expanded Alaskan Demand: The expanded demand was developed by reducing the timeliness and adding additional federal users: specifically, BLM Headquarters, EPA, BIA State and Headquarters, and the Forest Service.

The BLM state office demand remained the same except the coverage cycle was extended from 30 to 60 days while the OCS office demand was increased to provide monitoring of the total continental shelf with data delivered in 2 days. A cumulative Headquarters demand was also added. The Corps of Engineers demand was augmented by 10% of land area delivered in 1 day.

Again, the EPA demand, as modeled, represents a substantial data volume. This demand is identical to the expanded EPA CONUS demand. Similarly, the Forest Service demand was identical to CONUS.

The State of Alaska demand is 50% of land area monitored every 180 days and 10% of the land monitored every 14 days with timeliness of 5 and 2 days, respectively.

The three-scene unspecified demand was reduced from 5-day to 1-day timeliness. Table 5-5 indicates the specific agency demands.

Table 5-5

Expanded Alaskan Demand

User Designation	User	Timeliness (days)	Coverage Cycle (days)	Probability of Demand
107	BLM, OCS Office all continental shelf	2	30	0.333
112	BLM, State Office, all land	9	60	0.152
131	BLM, Headquarters cumulative	2	30	0.333
133	BLM, Headquarters cumulative	9	60	0.152
136	EPA, 10% land	5	7	0.5
138	EPA, 50% land	2	60	0.152
140	EPA, 20% continental shelf	5	14	0.5
144	USACE, all district area	5	30	0.333
146	USACE, 10% all district area	1	1	0.5
183	Forest Service, national forests	2	30	0.333
191	Forest Service, national forests	2	30	0.333
301	State Government, 50% land	5	180	0.05
303	State Government, 50% land	2	14	0.5
504	Unspecified, 1 scene	1	14	0.5
505	Unspecified, 2 scenes	1	14	0.5

Using the same equations specified in Section 5.3, the probable demand volumes were derived for Alaska. These are given in Table 5-6.

Table 5-6

Probable Demand Volumes

- Alaska -

	Probable No. of Requests/ Coverage Cycle		Probable Volume/Request/ Coverage Cycle, Gigabits	
	30/7	10/12	30/7	10/12
Nominal Case	83	83	4.9	44.4
Expanded Case	185	185	3.0	27.2

By comparison of Table 5-6 with Table 5-3 it can be seen that the probable Alaska demand, as modeled, represents approximately one-third of the CONUS demand for 30m data and about one-fifth for 10m data. It should be noted that the alaska demand, by including the continental shelf, may overstate actual demand for this region.

SECTION 6.0

NETWORK CONFIGURATION

The purpose of this Section is to provide a definition of the network elements, thereby introducing the alternatives.

The network can be categorized into transmission and processing elements. Processing can be further reduced to 'correction' and 'analysis' functions. In this study, the term preprocessing refers to correction functions. While the line between correction and analysis is fuzzy, it was assumed that all delivered products would be in a common-coordinate system registered to accuracies now being proposed for the National Data Processing Facility. Preprocessing may be performed, in whole or in part, at a regional facility or entirely at a central facility. This study is limited to preprocessing functions only.

The following terminology has been used to describe network nodes throughout this study.

Earth-Resource Satellite (ERS)	Low altitude-polar orbiter
Data Relay Satellite (DRS)	Synchronous Satellite
Regional (reception)	Regional terminal receiving ERS data, either directly or by relay
Central (processing)	Central facility that processes all ERS data
Central (distribution)	Central facility that distributes preprocessed data to all users
Area	Single facility that provides final analyzed products to multiple users

Given these definitions, the number of possible transmission links in a network are shown in Figure 6-1.

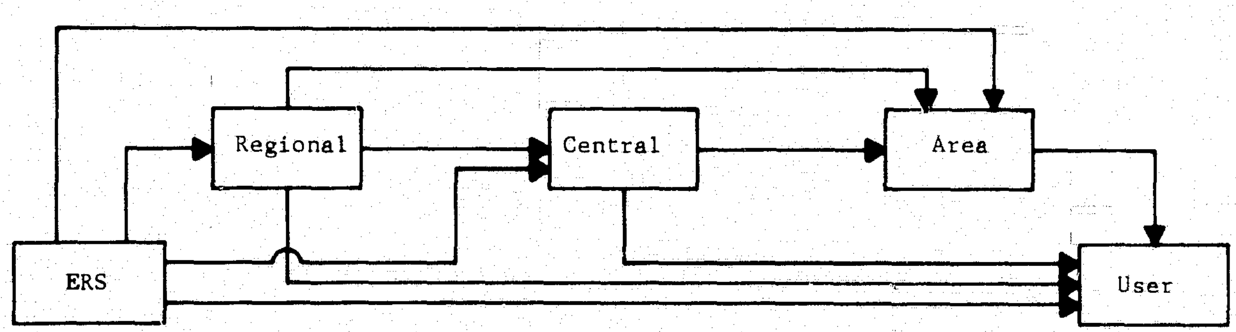

Figure 6-1. Possible Network Transmission Links

Given a data relay satellite, each of these links has two alternatives, direct, as shown, or relayed through a DRS. Thus, there are 20 possible types of links. Furthermore, each of these types is characterized by different link capacities depending on the number of regional and area centers as well as the number of users and their specific demands. Of this number of possible links, the ERS-to-user link was not considered in this study. To adequately analyze this link, a definite identification of specific users associated with specific areas of coverage is required. Furthermore, the ERS-to-Area link becomes identical to the ERS-to-regional link when the number of Area centers is small. This study did not address the dissemination problems associated with ERS-to-Area centers for more than four Area centers; e.g., the regional case. Thus, this study addressed 16 link types.

As stated previously, only preprocessing functions were considered. The specific functions identified (see Section 9.0) are:

Record and Playback
Reformatting
Address Insertion
Channel Redundancy Removal
Quick-Look Data Extraction
Cloud-Cover Extraction
Radiometric Correction
Geometric Correction
Archival Storage
Data Routing

As a consequence of a previous study [1], it was further assumed that none of the foregoing functions would be performed in space. Part or all of these functions could be performed either at a regional or at a central facility.

Quick-look data, as used herein, refers to a sub-set (either by area, band selection, or resolution reduction) of the primary dara transmitted to the user under high priority and prior to correction (radiometric and geometric) preprocessing. This data set results in four additional link types: Namely, quick-look regional to area, regional to user, central to area, and central to user. Again, each of these links could be implemented directly or by satellite relay.

In summary, this study evaluated 24 transmission link types involving 6 nodal types and 10 preprocessing functions that could be performed at either of two types of nodes.

SECTION 7.0

INTRODUCTION

In the earth-resources data dissemination network, two basic types of data transmission links exist: (1) raw data transmission from the ERS to an earth terminal (either direct or via a data relay satellite) and (2) data transmission (raw or preprocessed) from one earth location to another. In this section, we will consider these two types of links separately. Key parameters are derived and cost-performance data is presented.

7.1 ERS-to-Earth Data Link

7.1.1 Direct Link: The ERS generates digital data at rates of 102 Mbps for the 30m/7-band case, and 1.58 Gbps for the 10m/12-band case (see Section 3.2). This section investigates the feasibility of transferring this data in real time from the ERS to an earth terminal. Real-time transmission via a synchronous data relay satellite (TDRS) is discussed in Section 7.1.2. Techniques for reducing the data transmission rate at the satellite by means of data compression were not considered in this study. The feasibility of performing data compression on board the satellite was investigated by Wintz in a separate study for NASA [1].

7.1.1.1 Choice of Frequency Band: The existing LANDSAT links operate at 2200 to 2300 MHz. The total bandwidth available is 100 MHz, which might be sufficient to handle the 30m/7-band case. However, this band is already in heavy use by other space programs, and the likelihood of the entire band being allocated to an ERS program, even on a time-shared basis, seems small. Therefore, to achieve wider bandwidths, the use of higher frequencies will be examined.

A frequency band at 8400 to 8500 MHz is available for space-to-earth links, and is already in use by the Deep-Space Network. For the same reasons cited above, the use of X-band does not seem likely

Table 7-1 lists the frequency bands allocated for satellite-ground communications above 10 GHz. From the standpoint of cost, technology risk, and link outages caused by rain attenuation, the lower frequency bands are preferred. On the other hand, higher frequency bands are preferred from the standpoint of bandwidth availability and freedom from restrictions due to band sharing with other services.

The most power- and bandwidth-efficient digital modulation technique available today is quadriphase modulation (QPSK). Using this technique, digital data can be transmitted over a channel with bandwidth equal to 0.6 to 1.0 of the data rate (depending upon the channel phase linearity). Theoretically, a channel bandwidth equal to 0.5 the data rate is sufficient. However,

Table 7-1*

Frequency Allocations for Space Utilization (WARC - 1971)

INTERNATIONAL			UNITED STATES		
Region 1 GHz	Region 2 GHz	Region 3 GHz	Band GHz	Government Allocation	Non-Government Allocation
10.95 - 11.2 FIXED FIXED-SATEL- LITE (Space-to- Earth) (Earth-to-Space) MOBILE	10.95 - 11.2 FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE		10.95 - 11.2		FIXED FIXED-SATELLITE (Space-to-Earth) (International Operations)
11.45 - 11.7 FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE			11.45 - 11.7		FIXED FIXED-SATELLITE (Space-to-Earth) (International Operations)
12.5 - 12.75 FIXED-SATEL- LITE (Space-to-Earth) (Earth-to-Space)	12.5 - 12.75 FIXED FIXED-SATEL- LITE (Earth-to-Space) MOBILE except aeronautical mobile	12.5 - 12.75 FIXED FIXED-SATEL- LITE (Space-to-Earth) MOBILE except aeronautical mobile	12.5 - 12.75		FIXED FIXED-SATELLITE (Earth-to-Space
			12.7 - 12.75		FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE
14 - 14.3 FIXED-SATELLITE (Earth-to-Space) RADIONAVIGATION 408A			14.0 - 14.2	RADIONAVIGATION Space Research (Earth-to-Space)	FIXED-SATELLITE (Earth-to-Space) RADIONAVIGATION Space Research (Earth-to-Space)
			14.2 - 14.3	RADIONAVIGATION	FIXED-SATELLITE (Earth-to-Space) RADIONAVIGATION
14.3 - 14.4 FIXED-SATELLITE (Earth-to-Space) RADIONAVIGATION-SATELLITE			14.3 - 14.4	RADIONAVIGATION- SATELLITE	FIXED-SATELLITE (Earth-to-Space) RADIONAVIGATION- SATELLITE

* Data drawn from Office of Telecommunications Policy (OTP) manual.

Table 7-1 (Continued)

INTERNATIONAL			UNITED STATES		
Region 1 GHz	Region 2 GHz	Region 3 GHz	Band GHz	Government Allocation	Non-Government Allocation
14.4 - 14.5	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE		14.4 - 14.5	FIXED MOBILE Space Research (Space-to-Earth)	FIXED-SATELLITE (Earth-to-Space) Space Research (Space-to-Earth)
17.7 - 19.7	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE		17.7 - 19.7		FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE
19.7 - 21.2	FIXED-SATELLITE (Space-to-Earth)		19.7 - 20.2		FIXED-SATELLITE (Space-to-Earth)
			20.2 - 21.2	FIXED-SATELLITE (Space-to-Earth)	
27.5 - 29.5	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE		27.5 - 29.5		FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE
29.5 - 31	FIXED-SATELLITE (Earth-to-Space)		29.5 - 30		FIXED-SATELLITE (Earth-to-Space)
			30 - 31	FIXED-SATELLITE (Earth-to-Space)	
40 - 41	FIXED-SATELLITE (Space-to-Earth)		40 - 41	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE
50 - 51	FIXED-SATELLITE (Earth-to-Space)		50 - 51	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE

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Table 7-1 (Continued)

INTERNATIONAL			UNITED STATES		
Region 1 GHz	Region 2 GHz	Region 3 GHz	Band GHz	Government Allocation	Non-Government Allocation
92 - 95	FIXED-SATELLITE (Earth-to-Space)		92 - 93	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE	FIXED MOBILE
			93-95	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE
102 - 105	FIXED-SATELLITE (Space-to-Earth)		102 - 103	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE	FIXED MOBILE
			103 - 105	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE
140 - 142	FIXED-SATELLITE (Earth-to-Space)		140 - 141	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE	FIXED MOBILE
			141 - 142	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE	FIXED FIXED-SATELLITE (Earth-to-Space) MOBILE
150 - 152	FIXED-SATELLITE (Space-to-Earth)		150 - 151	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE	FIXED MOBILE
			151 - 152	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE	FIXED FIXED-SATELLITE (Space-to-Earth) MOBILE
265 - 275	FIXED-SATELLITE		265 - 275	FIXED FIXED-SATELLITE MOBILE	FIXED FIXED-SATELLITE MOBILE

this ratio would be difficult to achieve in practice, especially at high data rates. (Note that COMSAT Labs and others have successfully demonstrated the transmission of 60 Mbps through a 40-MHz channel.)

Examination of Table 7-1 shows a 100-MHz bandwidth available at 14.4-14.5 GHz for space-to-earth transmission. This band is recommended for the 102-Mbps ERS-to-earth data link required for the 30m/7-band system. This band is also close to the band used for the TDRS, an advantage if an ERS were to have the capability of working with TDRS or a direct readout ET. Table 7-1 shows a 2.5-GHz bandwidth allocation at 20 GHz. Of this, the upper 1.0 GHz is reserved for U.S. government use, which would be adequate for the 1.58-Gbps link. The lower 1.5-GHz portion of the band is assigned to future domestic satellite downlinks. Its use by a future ERS could lead to a significant radio interference problem whenever an ERS passed through a beam from a synchronous communication satellite, and both satellites' earth terminals were located in the same region.

The next frequency band allocated for satellite-to-earth transmission is 40-41 GHz. This band is relatively free of potential users in the 1985-1995 time period and could be used for the 1.58-Gbps data link. It may also be possible to widen this bandwidth allocation at the next WARC meeting (1979). This would be desirable to ease the complexity of phase equalization required to transmit a 1.58-Gbps data rate through a 1.0-GHz bandwidth channel. On the other hand, 40 GHz is more susceptible to rain attenuation and requires more advances in rf component technology.

For purposes of sizing and costing the ERS data reception earth terminals, the use of the 14.45-GHz band for the 30m/7-band ERS and the 20.7-GHz band for the 10m/12-band ERS is recommended. An alternative band at 40.5 GHz will also be considered.

Optical links, using lasers, were not considered because of the attenuation effects of clouds.

7.1.1.2 ERS-to-ET Link Budget: Table 7-2 summarizes the basic link equation used for sizing the satellite and earth terminals. Table 7-3 derives the received carrier-to-noise power density (C/kT) required to demodulate a QPSK signal with a bit error rate (BER) of 10^{-6}. Combining the equations from these two tables, we obtain the following expression for the required ERS EIRP:

$$P = 20 \log F + 10 \log R - 49.9 - \frac{G}{T} \quad \text{dBW} \tag{7-1}$$

where F is the carrier frequency in MHz

R is the data rate in Mbps

$\frac{G}{T}$ is the earth terminal sensitivity in dB/^{o}K

Table 7-4 lists the results of applying Eq. (7-1) to the three cases of interest.

Table 7-2

Basic Link Budget - ERS-To-Earth Terminal (ET)

BUDGET ITEM	VALUE	
Satellite EIRP	P	dBW
Space Loss[1] (F in MHz)	-102.1 - 20 log F	dB (Hz)
Polarization, Atmospheric Losses (Clear Weather)	-3.0	dB
ET Antenna Gain	G	dB
ET Receive System Temperature	T	dB
Boltzman's Constant (K)	-228.6	$dBW/^{o}K/Hz$

Therefore

$$C/kT = P + \frac{G}{T} + 123.5 - 20 \log F \quad dB(Hz)$$

(1) ERS Altitude = 920 km
ET Elevation Angle = 5^{o}
Slant Range = 3034.5 km

Table 7-3

Required C/kT For QPSK Data Link

Theoretical E/N_o (For BER = 10^{-6})	10.6 dB
Degradation due to link imperfections	3.0 dB
Data Rate (R) (Mbps)	60 + 10 log R dB(Hz)
Required C/kT	73.6 + 10 log R dB(Hz)

Table 7-4

Required ERS EIRP For 3 Cases

Frequency Band (GHz)	14.5	20.7	40.5
Data Rate (Mbps)	102	1580	1580
ERS EIRP (dBW)	$53.5 - \frac{G}{T}$	$68.4 - \frac{G}{T}$	$74.2 - \frac{G}{T}$

7.1.1.3 Earth Terminal Sensitivity: The state-of-the-art of earth terminals for high frequency bands is advancing rapidly. For example, the Japanese are developing 10-meter antennas for operation at 20- and 30-GHz synchronous satellite service. Figure 7-1 indicates the state-of-the-art low-noise amplifiers as a function of frequency. Uncooled paramps with 1-GHz bandwidth are being developed at 20 GHz. At 40 GHz, more development is required. However, the value of an extremely low-noise receiver (less than 100°K) is questionable because, at the higher frequencies, the antenna temperature is highly influenced by clouds or moisture in the atmosphere. At lower elevation angles, the antenna noise temperature could approach 290°K at 40 GHz. For our purposes, receiving system temperatures shown in Table 7-5 have been assumed.

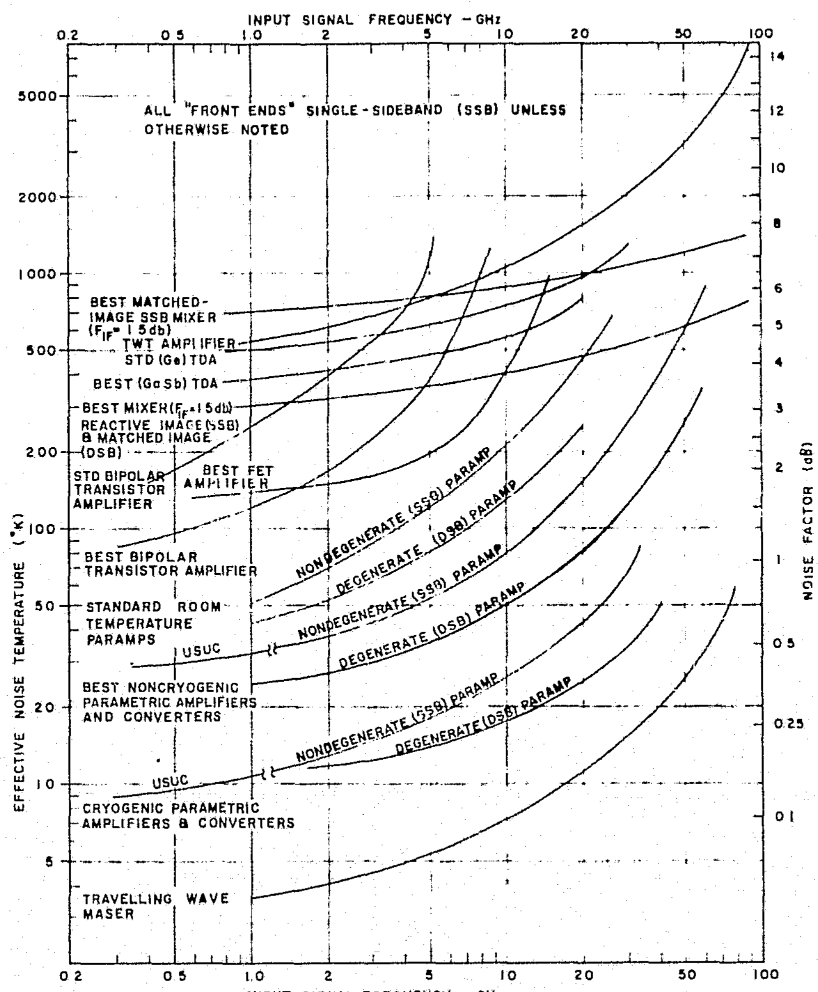


Figure 7-1. Amplifier Noise Temperature State-of-the-Art*

* From H. C. Okean and P. P. Lombardo, "Noise Performance of M/W and MM-Wave Receivers," the Midrowave Journal: January, 1973.

Table 7-5

Earth Terminal Sensitivity Derivations

Frequency (GHz)	14.5	20.7		40.5	
System Noise Temperature (^{o}K)	170	200		400	
Antenna Beamwidth (Deg)	0.3	0.3	0.1	0.3	0.1
Antenna Diameter (m)	4.9	3.4	10	1.7	5.0
(ft)	16	11	33	5.5	16.5
Gain (55% Eff.) (dB)	54	54	64	54	64
Pointing Loss (dB)	1.0	1.0	1.0	1.0	1.0
Line Losses (dB)	1.0	1.0	1.0	1.0	1.0
Net Gain	52	52	62	52	62
G/T (dB/^{o}K)	30	29	39	26	36

The diameter of the ET antenna is limited by the surface tolerances, and by the beamwidth. High-precision antenna surfaces have been successfully achieved at 40 GHz and higher in radio telescope applications. The narrow beamwidth is more of a problem since the antenna must track at fairly high rates. A minimum beamwidth of 0.1^{o} and more easily achieved beamwidth of 0.3^{o} have been postulated. A 1-dB pointing loss has also been assumed. These parameters are shown in Table 7-5.

The feasibility of achieving these angular accuracies was not considered in detail. The maximum angular rate of the ERS is 0.055^{o}/sec., which occurs for an overhead pass (altitude of 710 km). The conventional azimuth-elevation mount would not be suitable for tracking overhead passes because of the high slewing rates encountered in azimuth. An X-Y mount, with the "key hole" lying in the east-west direction, appears more suitable.

7.1.1.4 Rain Attenuation: As the carrier frequency increases, the path loss attenuation introduced by rainfall also increases. Table 7-6 summarizes the attenuation expected for a rainfall rate of 10 mm/hr., which corresponds to a moderate rain storm with duration up to 20 minutes. The probability of the rainfall rate exceeding this level depends upon the location of the earth terminal but, typically, runs around 0.002; thus, we might, on the average, lose data from one pass out of 500. Whether or not this loss is significant depends on the quality and urgency of earth resources data being collected at the time of high rainfall. Obviously, the chances of cloud cover over the area of interest would be higher when the earth terminal is encountering rain, especially at higher elevation angles.

Table 7-6

Predicted Rain Attenuation For 10 mm/hr Rainfall Rate

Frequency (GHz)	14.5	20.7	40.5
Attenuation Coefficient - dB/km 10 mm/hr Rainfall Rate	0.4	1.0	3.0
Effective Distance - km			
5° elevation	16	16	16
10° elevation	10	10	10
20° elevation	6	6	6
Path Attenuation - dB			
5° elevation	7	16	48
10° elevation	4	10	30
20° elevation	3	6	18
PROBABILITY $>$10 mm/hr : 0.002*			

* "Propagation Data Required for Space Telecommunication Systems", Draft Report AD/5, C.C.I.R. Conclusions of the Interim Meeting of Study Group 5 (Propagation in Non-Ionized Media), Geneva, 5-18 April 1972, pp. 259-270.)

Table 7-6 shows how the rainfall attenuation increases with frequency. As will be shown in the next section, link designs with up to 20-dB margin are feasible. Thus, the 14.5- and 20.7-GHz links can be accommodated at 5° elevation angles, whereas, the 40.5-GHz link will become inoperative at elevation angles much below 20°. The 5° and 10° elevation contours for the lower ERS orbit (710 km) for ERS readout terminals at Fairbanks and Sioux Falls and the 20° elevation contours for the 900-km ERS orbit for readout terminals at Fairbanks, Goldstone, Sioux Falls, and Greenbelt are shown in Figures 7-2 and 7-3, respectively. A conclusion from these figures is that, if the 40.5-GHz band is used, three earth terminals rather than one must be used in the lower-48 states (Goldstone and Greenbelt and one somewhat more southerly than Sioux Falls -- say, Kansas City) to maintain the higher elevation angle. Alternatively, for 40.5-GHz links, a single ET could be located in a desert area where rainfall seldom occurs. However, for the USA, such desert areas are too far west to support ERS passes over the east coast, especially at the 710-km altitude.

Another possible solution for rain attenuation is space diversity. For medium to heavy rains, a separation of twenty-five miles virtually eliminates fading. The obvious drawback to space diversity is that two ground stations are required, both manned simultaneously, and a wideband link must be established between them. There is no actual technology constraint in the use of space diversity; however, the added cost is significant.

It should be emphasized that the parameters discussed above are only estimates based on the 1972 CCIR study [2]. Considerable data is being or will be collected by a number of investigations which will provide a more accurate assessment of the rainfall attenuation problem in the future.

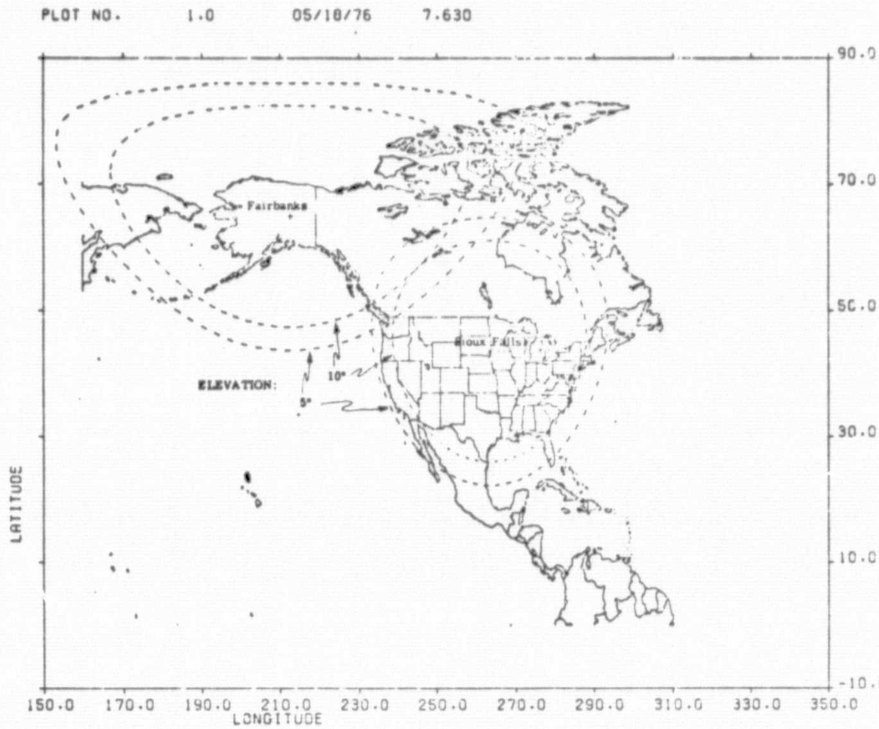


Figure 7-2. 5° and 10° Elevation Contours for ERS Readout Terminals at Fairbanks, AK and Sioux Falls, SD - ERS Altitude = 710km

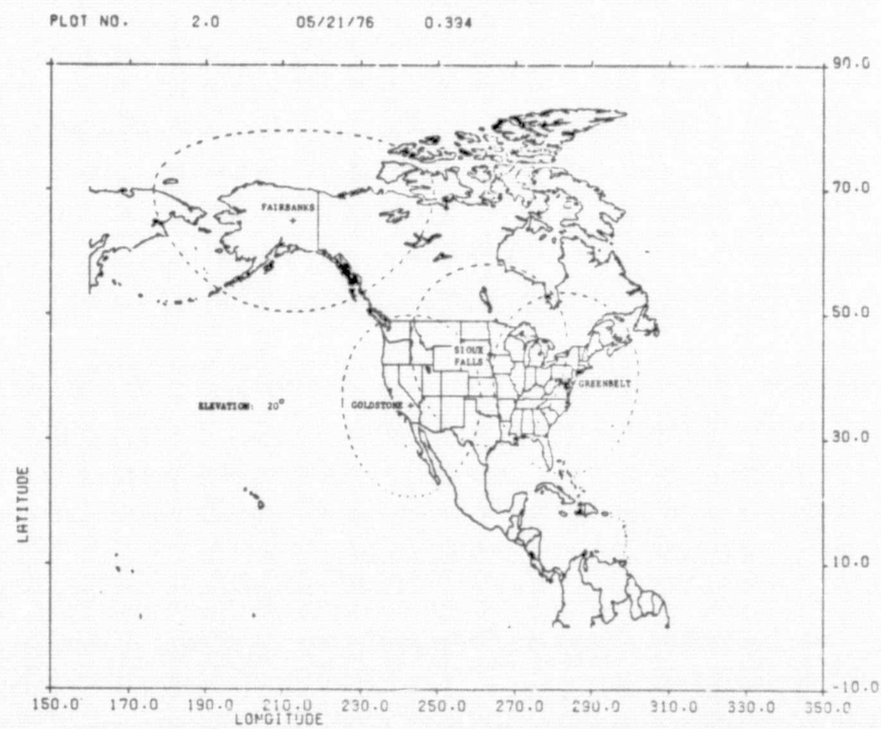


Figure 7-3. 20° Elevation Contours for ERS Readout Terminals at Fairbanks, AK, Goldstone, CA, Sioux Falls, SD, and Greenbelt, MD - ERS Altitude = 900km

7.1.1.5 <u>ERS EIRP</u>: The satellite EIRP is derived by combining the results of Tables 7-4 and 7-5. The required EIRP is shown in Table 7-7 for the cases considered.

Table 7-7

ERS-ET Link Configurations

FREQUENCY - GHz	14.5		20.7				40.5			
DATA RATE - Mbps	105		1580				1580			
ET NOISE TEMP - ^{o}K	170		300				400			
ET BEAMWIDTH - deg.	0.3		0.3		0.1		0.3		0.1	
ET DIAMETER - m	4.9		3.4		10		1.7		5.0	
ET G/T - dB/^{o}K	30		29		39		26		36	
SATELLITE EIRP - dBW	23.5		39.4		29.4		48.2		38.2	
SATELLITE ANTENNA BEAMWIDTH - deg.	60	2.5	2.5	1.25	2.5	1.25	2.5	1.25	2.5	1.25
PEAK ANTENNA GAIN - dB	8	36	36	42	36	42	36	42	36	42
ANTENNA POINTING LOSS - dB	3	1	1	1	1	1	1	1	1	1
LINE LOSS - dB	1	2	2	2	2	2	2	2	2	2
NET ANTENNA GAIN - dB	4	33	33	39	33	39	33	39	33	39
SATELLITE ANTENNA DIAMETER - m	-	0.6	0.4	0.8	0.4	0.8	0.2	0.4	0.2	0.4
ft	-	2	1.4	2.8	1.4	2.8	0.7	1.4	0.7	1.4
TRANSMITTER POWER - dBW	19.5	-9.5	6.4	0.4	-3.6	-9.6	15.2	9.2	5.2	-0.8
- W	90	0.11	4.4	1.1	0.44	0.11	33	8.3	3.3	0.8
RAIN MARGIN* - dB	7	7	16	16	16	16	18	18	18	18
TRANSMITTER POWER - W	450	0.55	175	44	18	4.4	2100	520	210	50

* 5^{o} elevation at 14.5 and 20.7 GHz; 20^{o} elevation at 40.5 GHz.

The ERS antenna gain is determined by size constraints and the ability to steer the antenna so that it is accurately pointing toward the earth terminal at all times. The size of the antenna is insignificant for the frequency bands of interest, so the beamwidth becomes the major design constraint. In Table 7-7, three beamwidths are assumed for the satellite antenna: 60^{o}, 2.5^{o}, and 1.25^{o}. The 60^{o} antenna requires little or no antenna pointing mechanism, (other than pointing the axis toward earth center). The gain toward earth edge is only 5 dB. For the 14.5-GHz link, a transmitter power of 90 watts is necessary to establish the link. On the other hand, if a steerable antenna with a 2.5^{o} beamwidth is used, the same link can be established with only a 0.11-watt transmitter.

At higher frequencies, only steerable antennas are considered. This technology is now under development for use with the TDRS, and should be available for ERS in the 1985-1995 time period. Note that a 1-dB pointing loss was assumed, which corresponds to a pointing error of 0.3 times the 3-dB beamwidth. This accuracy is readily achievable.

Table 7-7 also lists the margin required to overcome rainfall attenuation at 5° or 20° elevation (see Table 7-6). The bottom line gives the required satellite power. A minimum elevation of 20° was assumed for the 40.5-GHz band because higher transmitter powers to overcome rain attenuation at lower elevation angles do not appear feasible in the immediate future.

A power output of 0.55 watts at 14.5 GHz is well within the TWTA state-of-the-art, as shown in Table 7-8. However, solid-state devices (FETs) are not available which will generate 1-2 watts at X-band. Nevertheless, one may expect the 14.5-GHz transmitter to be a solid-state device by 1985.

Table 7-8*

Satellite TWT

POWER LEVEL (WATTS)	FREQUENCY (GHz)				
	2.54	3.7 – 4.2	7.25 – 7.75	11.7 – 12.2	17.7 – 20.2
2-4		HUGHES FOR INTELSAT IV, NEC FOR CS	HUGHES FOR NATO III, DSCS II		HUGHES FOR PHILCO-FORD CS SATELLITE
8-15		TELEFUNKEN AEG FOR SYMPHONIE	WJ, HUGHES FOR DSCS III		NEC FOR CS SATELLITE
20				THOMSON-CSF AND TELEFUNKEN AEG FOR OTS, CTS INTELSAT V	
100-200	WJ FOR JPL			HUGHES AND LITTON FOR JAPANESE BROADCAST SATELLITE	
200-1000				SIEMENS AND TELEFUNKEN AEG FOR GERMAN TV SATELLITE	

* From C. L. Cuccia, "Millimeter Wave Spacecraft Technology," WDL IRDP Report; November, 1975.

At 20 GHz, TWTA's with power outputs up to 20 watts are being developed. A 50-watt TWTA should be feasible. At 40 GHz, no work is underway above 10 watts, as shown in Table 7-9. A 50-watt TWTA transmitter could be developed without too much difficulty, however.

Table 7-9*

Millimeter Wave Space Power Devices

DEVICE \ FREQUENCY	18-21 GHz	30 GHz	35-40 GHz	60 GHz
TWT	2.5 WATT TWT Hughes (ATS-6) 4.5 WATT TWT Hughes (JAPAN CS) 1,2.5,5,10,WATT TWT Hughes for AT&T	2 WATT TWT Hughes (ATS-6)	10 WATT TWT Watkins Johnson Hughes	10 WATT TWT Hughes
IMPATT AMPLIFIERS	29 dBm Output COMSAT Labs for COMSTAR	29 dBm Output COMSAT Labs for COMSTAR	50 mW for Classified Space Project	

* C. L. Cuccia

7.1.1.6 Conclusion - ERS-to-ET Direct Link: Table 7-10 summarizes the key parameters of the recommended links for transmission of data from the ERS to the earth terminal. It is seen that the 30m/7-band link is readily implemented with today's technology, whereas the 10m/12-band link would require considerable development, especially if the 40-GHz band was used.

Table 7-10

Recommended ERS-ET Links

Resolution/Spectral Bands	30/7	10/12	
Data Rate - Mbps	105	1580	
Frequency Band - GHz	14.4-14.5	20.2-21.2	40-41
Satellite Transmitter Power - Watts	0.55	18	50
Satellite Antenna Beamwidth - Degrees	2.5	2.5	1.25
Satellite Antenna Pointing Accuracy - Degrees	0.75	0.75	0.38
Satellite Antenna Diameter - m	0.6	0.4	0.4
Earth Terminal Diameter - m	4.9	10	5
Earth Terminal Beamwidth - Degrees	0.3	0.1	0.1
Earth Terminal Noise Temperature - °K	170	300	400
Channel Bandwidth - MHz	100	1000	1000
Rain Margin (10 mm/hr) - dB	7	16	18
Minimum Elevation Angle (with Rain) - Degrees	5	5	20

The cost of the recommended ERS Readout Terminal for the 30m/7-band link is summarized in Table 7-11.

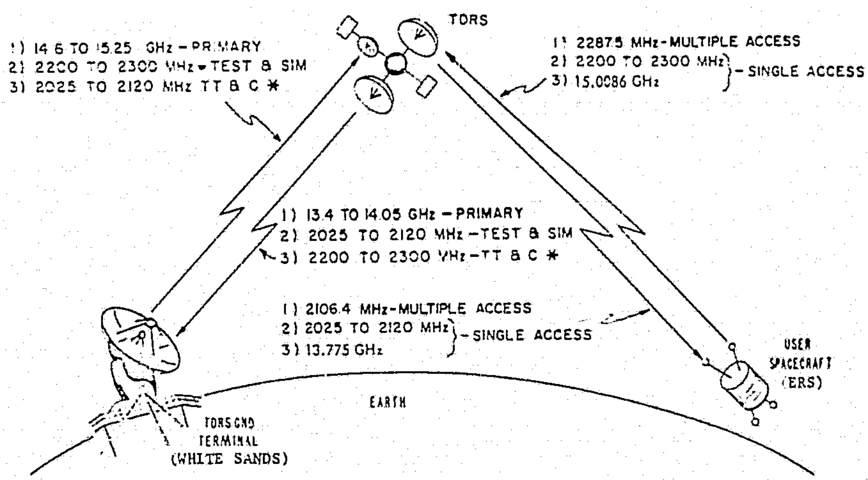
Table 7-11

Estimated Equipment Costs - ERS Readout Terminal
(30-meter/7-band link)

EQUIPMENT	COST ($K)
ANTENNA (5m, Automatic Tracking), FEED, MOUNT (Fully Steerable)	200
PARAMP LNR (Redundant, 100-110°K)	90
DOWN CONVERTER	20
RECEIVER/DEMODULATOR	25
TOTAL	335

7.1.2 ERS to Earth via Satellite Relay: An alternative to regional earth terminals for reception of raw ERT data is the use of a synchronous-satellite relay link. For the 30m/7-band (LANDSAT D) case, the NASA TDRS system should be available by 1985. In fact, LANDSAT D has been identified by NASA as a primary user of the TDRS.

Figure 7-4 shows the basic concept and frequency plan [3]. The primary single-access link is used. The ERS would be equipped with a transmitter and tracking antenna operating in the 14.6- to 15.25-GHz band. The data would be received by the TDRS and retransmitted to an earth terminal at White Sands, New Mexico. From there, the data would be demodulated, placed in buffer storage, and then retransmitted by suitable means to the data preprocessing facility.



* TRACKING, TELEMETRY AND COMMAND
- PRIMARY DURING LAUNCH PHASE
- BACKUP DURING OPERATIONAL PHASE

Figure 7-4. TDRS System Frequency Plan

In this study, use of TDRS for 30m/7-band data makes sense only for transfer of data collected over Alaska. The impact of TDRS on the network is to replace the wide-band data link from Fairbanks to Sioux Falls with a similar link from White Sands to Sioux Falls. Since the difference in costs between these two links is insignificant when using domestic satellites, the only advantage in using TDRS is the cost savings resulting from the elimination of an ERS readout station in Alaska.

However, the impact of this TDRS link on the ERS is significant. For the 30m/7-band case, a 102-Mbps link is required. From Table 7-12 (plotted in Figure 7-5), the required EIRP is 55.1 dBW. This translates to a 20-watt transmitter and a 5-foot diameter antenna on the ERS, continuously pointed to the TDRS with an accuracy of 0.5° (see Table 7-13). The impact of this data transmission system on the ERS complexity, size, power, and weight is considerably higher than the 550-milliwatt transmitter and 2-foot diameter antenna required for direct data transmission directly to an earth readout terminal (see Table 7-7).

Table 7-12*

Calculation for KSA Return Link

BER	10^{-5}
User EIRP (dB)	EIRP
Space Loss (dB)	-209.2
Pointing Loss (dB)	-0.5
Polarization Loss (dB)	-0.5
TDRS Antenna Gain (dB)	52.6 (55%)
P_s at Output of Antenna (dBW)	-157.6 + EIRP
T_s (Antenna Output Terminals) (°K)	893
KT_s at Output of Antenna (dBW/Hz)	-199.1*
P_s/KT_s (dB-Hz)	41.5 + EIRP
Transponder Loss (dB)	-2.0
Demodulation Loss (dB)	-1.5
PN Loss (dB)	0**
System Margin (dB)	-3.0
Required E_b/N_0 (dB - Hz) (Δ PSK)	-9.9
Achievable Data Rate (dB)	25.1 + EIRP
FEC Gain R = 2, K = 7 (dB)	5.2
***Achievable Data Rate (dB)	30.3 + EIRP

*Refer to appendix F for DG1 when generated simultaneously with DG2.

**-1 dB for DG1.

***This achievable data rate is the user's information rate. It should not be confused with the channel symbol rate which is twice the information rate.

* From TDRSS user's manual

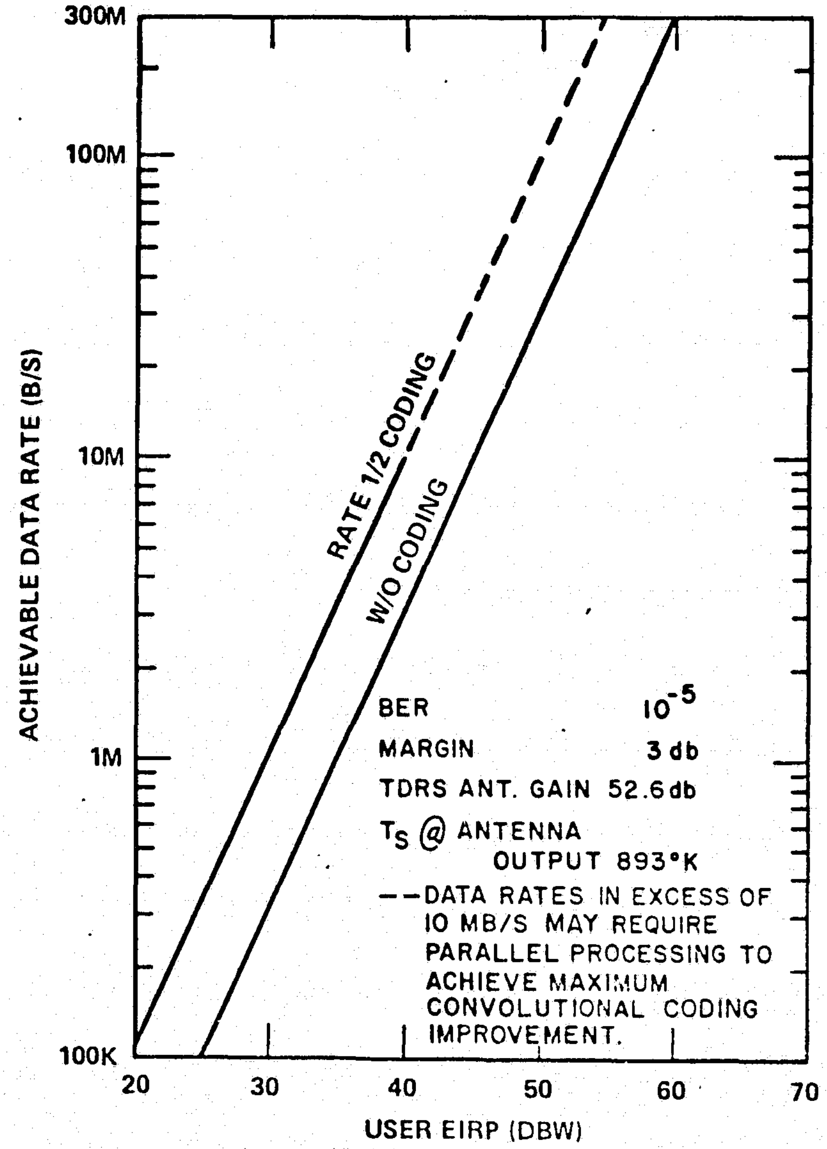


Figure 7-5.* KSA Return Link, Achievable Data Rate vs User EIRP
* From TDRSS user's manual.

Table 7-13

Generation of EIRP by ERS for Transmission of Data via TDRS

From Table 7-11: EIRP = 10 log R - 25.1 = 55.1 dBW

where R = 102 Mbps

Transmitter Power (20W)	13.0 dBW
Line Losses	- 1.9 dB
Antenna Gain (55%, 5 ft.)	45.0 dB
Pointing Loss (±0.5 deg.)	- 1.0 dBW
EIRP	55.1 dBW

C-2

The above discussion is based on uncoded transmission as, at present, error correction coding technology does not exist above 10 Mbps.

For the case of the 10m/12-band system, approximately 12 dB greater satellite EIRP would be required (assuming the TDRS bandwidth could be increased to approximately 1 GHz). Such an EIRP could be achieved with a 10-foot diameter antenna and an 80-watt TWTA, both of which could be implemented, but only with significant increase in the size, weight, and cost of the ERS.

Note that no plans presently exist to extend the capacity of the TDRS link beyond 300 Mbps. Therefore, TDRS can only be considered for use with the 30m/7-band ERS. On the other hand, technology is being developed by the DoD for satellite-to-satellite links with 1.0-Gbps capacity. These links employ laser beams, and an in-orbit test is planned in the early 1980 time period [4]. This technology could be extended to 1.58 Gbps to support the 10m/12-band requirement.

If the scope of the study had been expanded to include ERS coverage of other continents, then the use of TDRS becomes much more attractive. The cost of installing, operating and maintaining ERS receiving stations on foreign territory is expensive and inconvenient, which is the reason TDRS is being implemented.

As of April, 1976, no policy has been established for charging a user for services provided by TDRS. In the past, NASA has borne the cost of developing a system and a user paid for the operation of the system only while he was using it. However, TDRS is to be financed by private industry and leased to NASA and others, as required. At this time, there is no reliable cost data available as to what this service would cost to an earth-resources data user.

In conclusion, the use of TDRS does not appear justified for continental U.S. coverage, alone. For extended coverage missions, TDRS is probably a lower cost system compared to the cost of installing and operating additional direct readout terminals plus the cost of the trunking links to connect these terminals to the preprocessing center. However, the cost of the TDRS service to the user is not known, at present, and the presently planned system cannot handle a 10-meter, 12-spectral-band requirement.

7.2 Data Transmission Between Two Earth Locations.

There are five alternatives feasible, by current technology, for network data transmission from point to point or from point to points on the earth. These are:

1. Common carrier
   (a) landlines
   (b) satellite, carrier-owned terminal
2. Leased-carrier transponder, user-owned terminals
3. Add-on transponder, user-owned terminals
4. Existing low-earth-orbiting satellite relay
5. Microwave line-of-sight (LOS)

Of these, common-carrier landlines can be further categorized as digital and analog and as dedicated and metered. (With metered service, link charges are based on actual link use.)

The purpose of this section is to establish the costs incident to implementation and use of each of these alternatives. Cost comparisons among the alternatives will be deferred until Section 8 where estimates of network link parameters (i.e., required data rates, link lengths, and frequency and duration of link use) are developed.

7.2.1 Common-Carrier Transmission Alternatives: The nature of common carriers is that they provide end-for-end service; that is, given a data stream at point a, they will deliver data to point b. Although some of the carriers will lease bandwidth on their systems, this situation will not be addressed here. Two modes of service are available: (a) landlines and (b) satellite communications.

7.2.1.1 Common-Carrier Landline Service Costs: Landline service data rates are roughly constrained to the following: 2.4 kbps, 9.6 kbps, 56 kbps, and 1.544 Mbps. Representative rates for digital and analog, metered and dedicated, data service, excluding one-time installation charges, are shown in Table 7-14. The most important characteristic of landline common-carrier link costs is the distance dependency. (As link lengths increase, transmission alternatives whose costs are not dependent on distance become more attractive.)

Using the costs of AT&T's Dataphone Digital Service (dedicated) and of Datran's Datadial Service* (metered) as typical of landline transmission, this distance-dependent characteristic is shown explicitly in Figures 7-6 and 7-7 for either a half- or a full-duplex link. It should be noted that, as indicated in Table 7-14, the costs for 56 kbps and 1.544 Mbps metered service are merely estimates and, as such, are highly subjective. These cost curves include the fixed annual costs (i.e., independent of distance) given in Table 7-15.

* Subsequent to final drafting of this report, it was learned that DATRAN's services may no longer be available. [5]

Table 7-14

Charges for Landline Common-Carr

DATA RATE	SERVICE / CARRIER / CHARGE TYPE	DIGITAL METERED DATRAN** (Datadial Service)	DIGITAL METERED AT&T (56 kbps Switched Service)	DIGITAL DEDICATED AT&T (Dataphone Digital Service)	(Tele
2.4 kbps	FIXED ($)	155/END/MO.	N/A	90/END/MO.	
	MILEAGE ($/mi.)	2.5×10^{-6}/sec.	N/A	0.4/MO.	DAY NIGH
9.6 kbps	FIXED ($)	175 END/MO.	N/A	155 END/MO.	
	MILEAGE ($/mi.)	5.0×10^{-6}/sec.	N/A	0.9/MO.	
56 kbps	FIXED ($)	300/END/MO. (2)	275/END/MO. (3)	277.5/END/MO.	
	MILEAGE ($/mi.)	3.3×10^{-5}/sec.	500 mi. = 1.75/min. 1000 mi. = 2.25/min. 2000 mi. = 3.25/min.	4.0/MO.	
1.544 Mbps	FIXED ($)	2100/END/MO. (2)	N/A	1700/END/MO. + 60/mi./MO. (4)	
	MILEAGE ($/mi.)	1.7×10^{-4}/sec.	N/A	64/MO. 1st 200 mi. 50/MO. 2nd 300 mi. 40/MO. Remaining mi.	

* One-time installation charges not shown

** Subsequent to final drafting of this report, it was learned that DATRAN's

FOLDOUT FRAME /

Table 7-14

Landline Common-Carrier Service*

	ANALOG	
EDICATED	METERED	DEDICATED
AT&T phone Digital Service)	AT&T (Telephone + User Modem) (1)	AT&T (8)
/END/MO.	5/END/MO.	(a) (b) SH 5.00 20.0 LD 16.20 -- HD 37.90 -- LH -- 27.1
0.4/MO.	DAY 1.13×10^{-5}/sec. NIGHT 6.5×10^{-6}/sec.	SH 3.75 LD 2.71 HD .92
5 END/MO.	N/A (7)	Same as 2.4 kbps
0.9/MO.	N/A	Same as 2.4 kbps
.5/END/MO.	N/A	450/END/MO. (5)
4.0/MO.	N/A	13/MO.
00/END/MO. /mi./MO. (4)	N/A	683/END/MO. (6)
1st 200 mi. 2nd 300 mi. Remaining mi.	N/A	31.55/MO.

COMMENTS

(1) Costs are estimated for 500 miles between nodes (AT&T rates are based on zones) and do not include user modem.

(2) Estimated not presently available.

(3) Only available in Chicago, Los Angeles, San Francisco, New York, and Washington, D. C.

(4) Intercity interconnecting-link mileage.

(5) 48 kbps only (12 channels).

(6) 230 kbps only (60 channels).

(7) 9.6 kbps data can be sent on a metered (dial-up) link (with a Non-AT&T modem) but will not guarantee the link quality. To guarantee the quality at this transmission speed, AT&T requires conditioning which, of course means a dedicated link.

(8) SH-Short Haul (Total Circuit mileage - 25mi. or less)
LD-Low Density (Between Low Density Rate Centers or between Low Density & High Density Rate Centers)
HD-High Density (only between High Density Rate Centers)
LH-Long Haul (Intercity circuits over 25 miles)

(a) Channel Terminal Charges
(b) Station Terminal Charges

earned that DATRAN's services may no longer be available. [5]

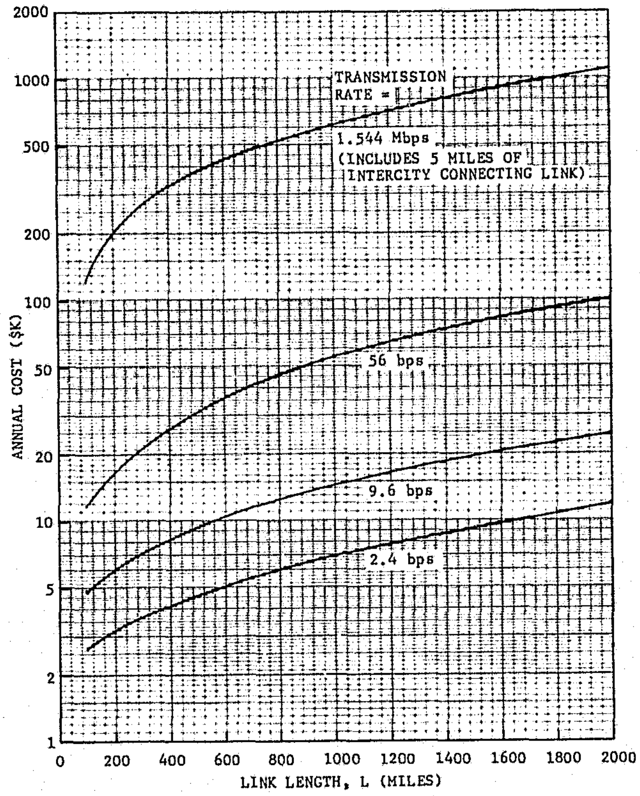


Figure 7-6. Annual Cost for AT&T Dataphone Digital Service (DDS) vs Link Length, L

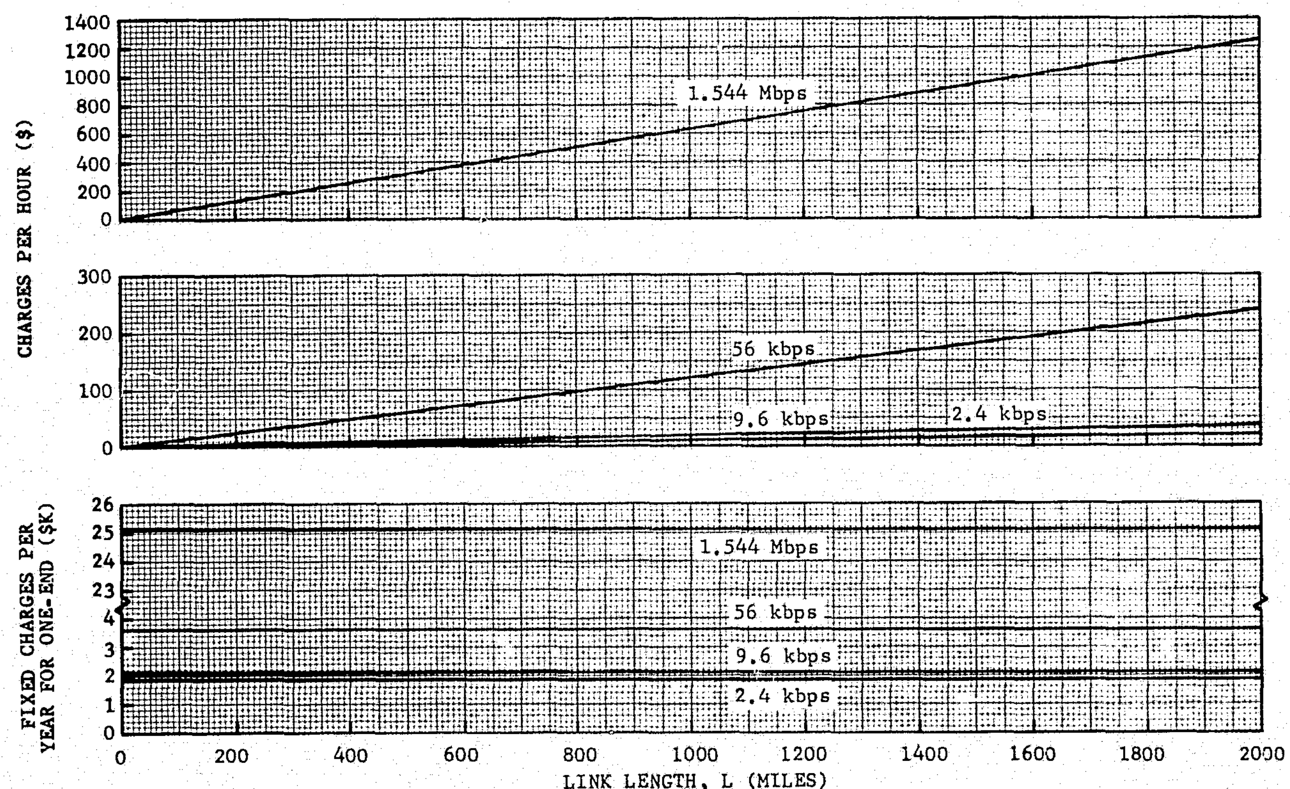


Figure 7-7. Charges for Metered Datran Datadial Service vs Link Length, L [5]

Table 7-15

Typical Fixed, or Distance-Independent, Annual Costs for Digital Landline Service

DATA RATE	FIXED ANNUAL COSTS	
	AT&T's DEDICATED DATA-PHONE DIGITAL SERVICE	DATRAN's METERED DATADIAL SERVICE* [5]
2.4 kbps	($1080) x 2 terminals	($1860) x 1.2 terminals
9.6 kbps	($1860) x 2 terminals	($2100) x 1.2 terminals
56 kbps	($3330) x 2 terminals	($3600) x 1.2 terminals
1.544 Mbps	($24000) x 2 terminals**	($25200) x 1.2 terminals

* It is assumed that the central distribution terminal is shared among 5 user links.

** Cost includes 5 miles of intercity interconnecting links.

The metered service may be cost effective for infrequent users. Based on the foregoing charge structure, the break-even (metered to dedicated) hours of link usage and the corresponding percent link utilization* were calculated for various distances as shown in Figures 7-8 and 7-9. (The general equation used in generating these curves is derived in Appendix E.) Metered transmission is cost effective at hours equal to or less than the designated hours. The parameter m indicates the number of user links that time share the metered terminal located at the central distribution facility.

These figures show that, for annual link usages of less than 400 hours, metered service is less costly than is dedicated service, regardless of link length. A second observation is that dedicated service should always be used when link utilizations are greater than about 25% and should be considered at even lower link utilizations on links longer than 100 miles.

7.2.1.2 Common-Carrier Landline Service Geographical Availability: In general, some form of analog service (e.g., AT&T) is available everywhere, though its cost can be significantly higher than that of digital service. (In the case of the 56-kbps services shown in Table 7-14, analog is from 2 to 3 times higher than digital service, depending on the length of the link (see Figure 7-10).) Digital service, by contrast, is not widely available. It is limited at the present time, according to published tariffs and expansion plans of the common and specialized common carriers, to the large metropolitan areas of the country -- approximately the 100 largest cities (or to an average of about two locations per state). Therefore, if remote users are to obtain common-carrier landline service, it must be on the more expensive analog links.

* 100% utilization is equivalent to full use during 16 hours per day, 365 days per year.

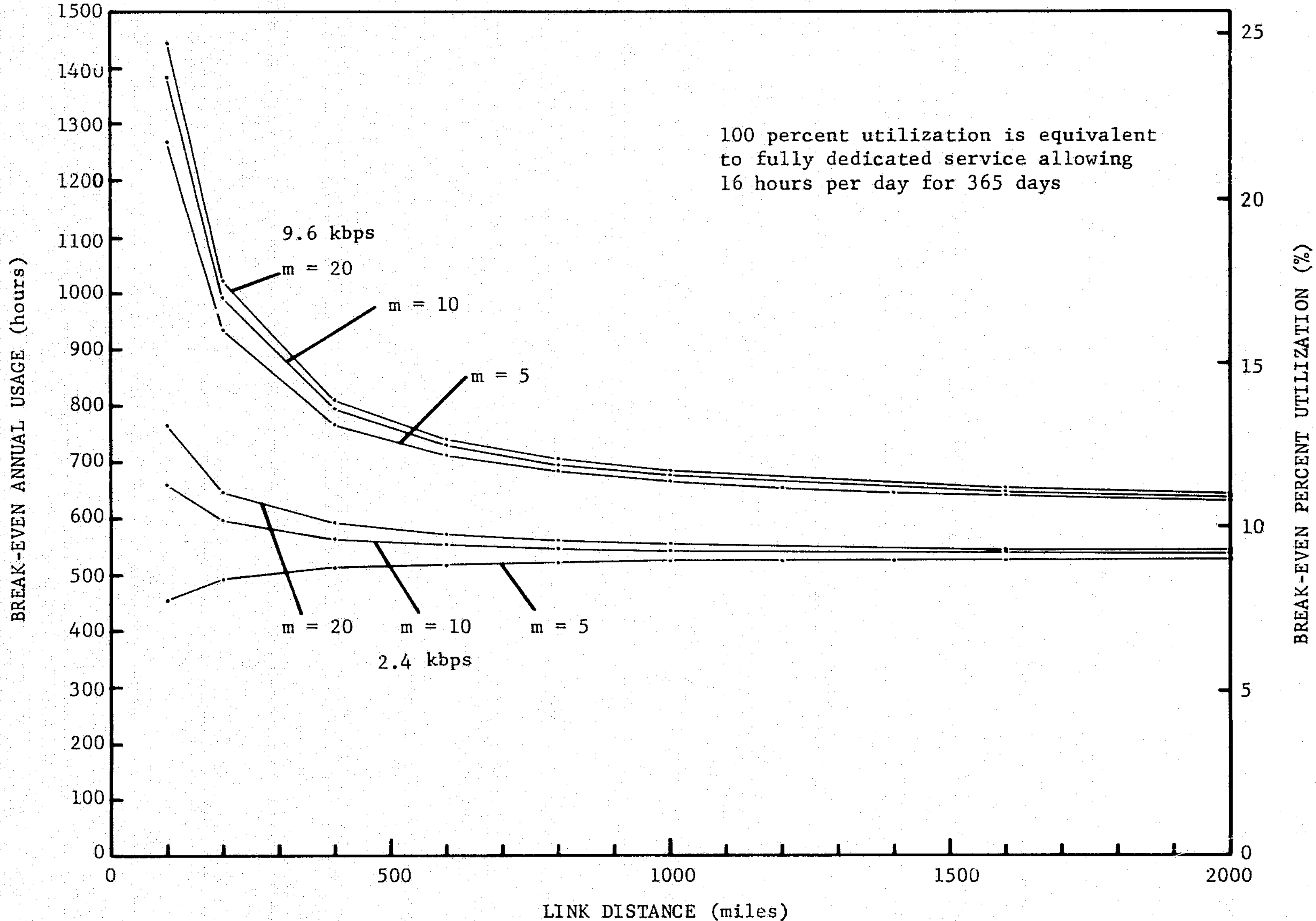


Figure 7-8. Break-Even (Metered-to-Dedicated) Hours of Link Usage and Percent Link Utilization vs Link Distance. (Metered service is cost effective at hours equal to or less than shown.)

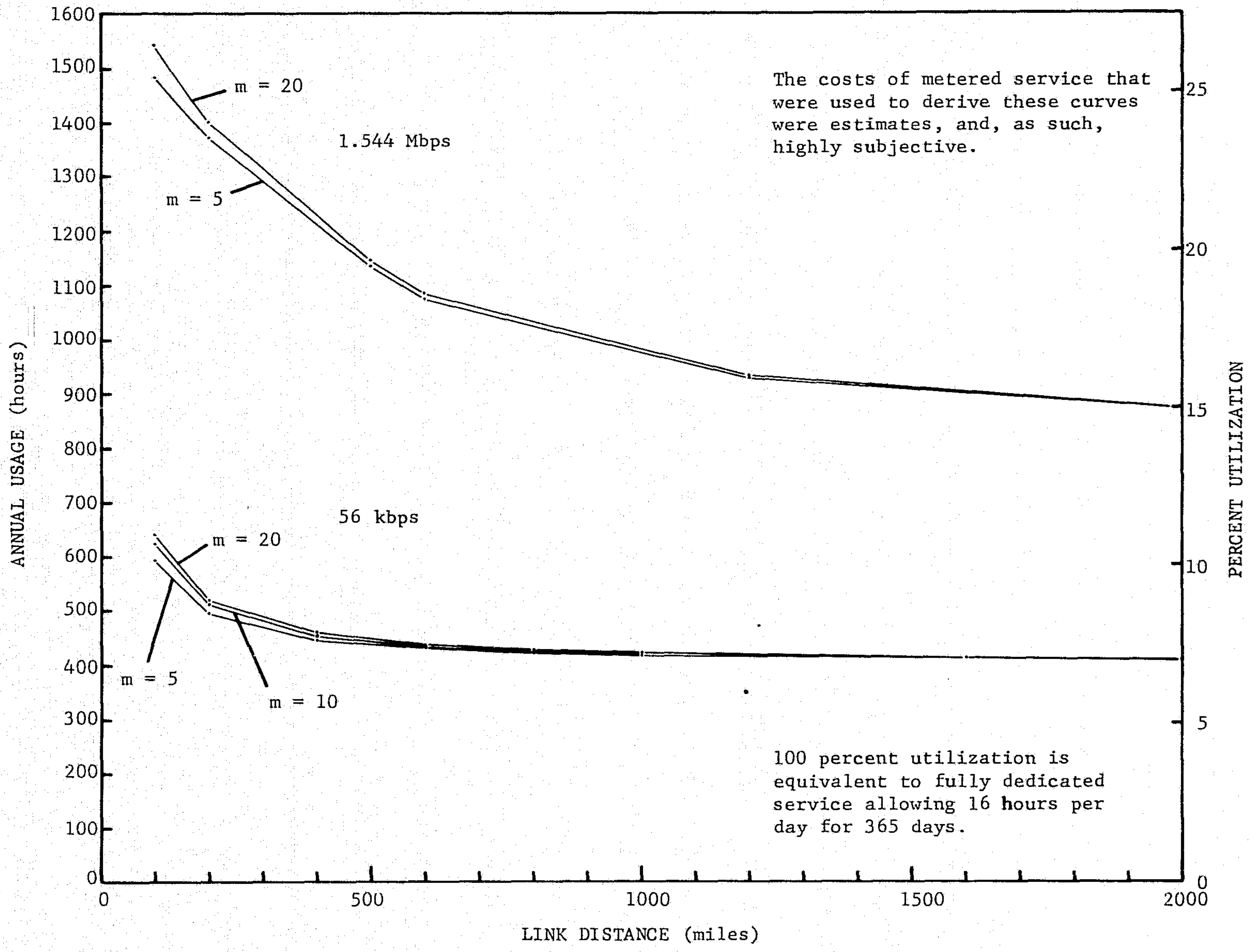


Figure 7-9. Break-Even (Metered-to-Dedicated) Hours of Link Usage and Percent Link Utilization vs Link Distance. (Metered service is cost effective at hours equal to or less than shown.)

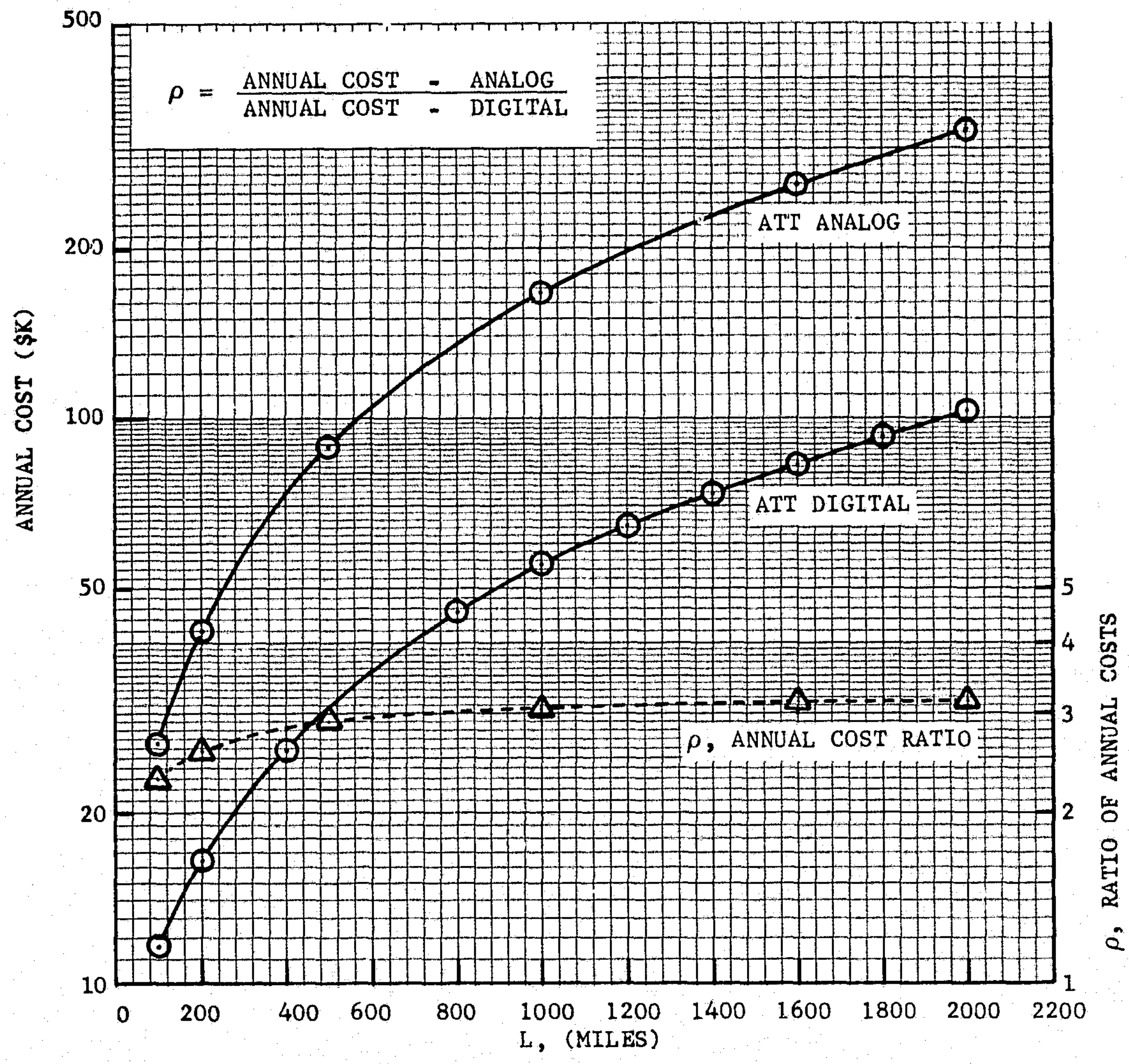


Figure 7-10. Total Annual Cost of Landline Analog and Digital Services at 56 kbps and Ratio, ρ, of these Total Annual Costs vs. Landline Link Length, L

Figure 7-11 indicates the location of digital service network nodes for landline common carriers. This service availability is for 1975 and will expand some by 1985-1995. Table 7-16 is a summary of the total number of nodes presently existing or proposed for leased-line services. Once the suitability of the available data rates has been determined, Figure 7-11 can be used with projected user locations to estimate the geographical limitation of using leased service.

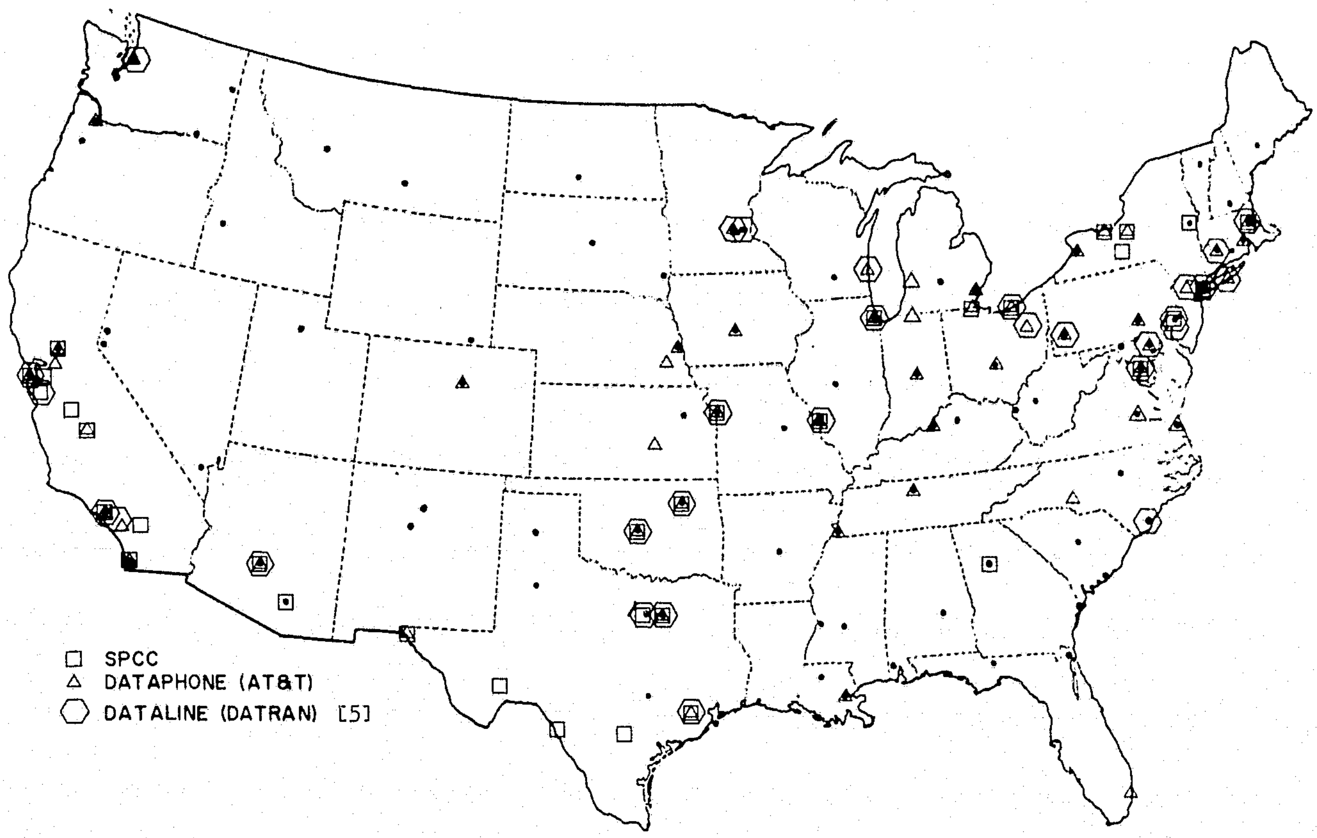


Figure 7-11. Geographical Distribution of Landline Common-Carrier Digital Transmission Service

Table 7-16

Number of Network Nodes for Landline Digital Common-Carrier Service

SERVICE	NODES (EXISTING AND PROJECTED)
AT&T DDS	100
Datran Datadial	50
SPCC*	40
AT&T 56 kbps Switching	5

* Southern Pacific Communications Corporation

7.2.1.3 <u>Common-Carrier Satellite Service Costs</u>: With recent favorable decisions by the FCC related to domestic satellites, a number of new carriers are offering, or will offer, both voice and data service.* Of these, all but SBS are providing this service in a hybrid manner; that is, leased landlines (AT&T, Datran [5] etc.) supplement the main satellite channel for

* RCA Globecom, American Satellite Corporation (ASC), Western Union, and SBS or Satellite Business Systems (IBM, COMSAT, and Aetna Life and Casualty).

end-to-end service to users. Due to the nature of this hybrid type service, charges are highly dependent on the user's location relative to the carrier's earth terminal.

The cost structure for this service is still based on distance, although this makes little sense when a satellite is employed. Table 7-17 summarizes the information obtained on tariffs applied to domestic satellite carriers. This information is somewhat scanty and may be expected to change due to the fact that all of these services are just beginning. Indeed, the rates stated therein for WESTAR for 1.544 Mbps service (1.2 MHz) are considerably out of line with those quoted to the government [6] by RCA Globecom (~$225K/year).

Comparing the published rate structures for landline and satellite common-carrier service, it may be seen that they yield essentially equivalent costs for equivalent services.

7.2.1.4 Common-Carrier Satellite Service Geographical Availability: The locations, actual and presently proposed, of earth terminals to be operated by these domestic satellite common carriers are given in Figure 7-12. It can be expected that, as domestic satellite systems mature, the locations of the ground stations will approximate the locations shown in Figure 7-11 for landline digital data service since it is reasonable to assume that both forms of service will follow geographical population distributions. What is clear, however, from both Figures 7-11 and 7-12 is the limitation of available carrier service to remote users. The earth-resource data users, as modeled, include many users where no common-carrier service exists. This fact alone (regardless of cost) would imply a severe limitation on using common carriers for data distribution.

7.2.2 Leased Transponder Transmission Alternative: The use of satellite transponders, or of a portion of the bandwidth and power of a transponder, to trunk raw and preprocessed data and to distribute preprocessed data to individual users appears very promising. The transmission alternative discussed in this section consists of satellite bandwidth and power leased on an existing commercial, synchronous satellite; system-owned trunking and up-link-distribution terminals; and user-owned down-link-distribution (i.e., receive-only) terminals (UOT's). The mix of private-user and common-carrier-type facilities thus envisioned may become subject to politically motivated restrictions; though, at present, there are no indications of major problems in this area. The concept of satellite service for user data dissemination is shown in Figure 7-13. The data of interest may be sent to each user in user-unique transmission or it could be "picked off" by any given user from a broadcast of all the data. The following subsections examine the cost of such a system.

Table 7-17

Charges for Satellite Common-Carrier Service (1)

SERVICE		WESTERN UNION TELEGRAPH CO.	AMERICAN SATELLITE CORPORATIO[N]
VOICE GRADE CHANNEL SERVICE 2.4 kbps	FIXED/END/MO.	100	105 With C-2 Conditioning +28 With C-4 Conditioning +58
	$/MILE/MO.	500 - 1000 miles .70 1000 - 2000 miles .42 2000 - 3000 miles .38	500 - 1000 miles .66 1000 - 2000 miles .43 2000 - 3000 miles .35
ALTERNATE DATA/VOICE CHANNEL SERVICE 4 kHz 9.6 kbps	FIXED/END/MO.	315 With C-1 Conditioning + 5 With C-2 Conditioning +19 With C-4 Conditioning +30	310
	$/MILE/MO.	500 - 1000 miles .70 1000 - 2000 miles .42 2000 - 3000 miles .38	500 - 1000 miles .66 1000 - 2000 miles .43 2000 - 3000 miles .35
ALTERNATE DATA/VOICE CHANNEL SERVICE 48 kHz 56 kbps	FIXED/END/MO.	470 + Modem With C-1 Conditioning + 5 With C-2 Conditioning +19 With C-4 Conditioning +30	No Charges Available
	$/MILE/MO.	500 - 1000 miles 7.56 1000 - 2000 miles 4.55 2000 - 3000 miles 4.13	500 - 1000 miles 7.92 1000 - 2000 miles 5.16 2000 - 3000 miles 4.20
WIDEBAND CHANNEL SERVICE In Increments of... 48 kHz	FIXED/END/MO.	See Footnote (2) & (3)	No Charges Available
	$/MILE/MO.	500 - 1000 miles 6.24 1000 - 2000 miles 4.29 2000 - 3000 miles 3.52	500 - 1000 miles 6.36 1000 - 2000 miles 4.08 2000 - 3000 miles 3.60
1.2 MHz	FIXED/END/MO.	See Footnote (2) & (3)	No Charges Available
	$/MILE/MO.	500 - 1000 miles 126.05 1000 - 2000 miles 75.84 2000 - 3000 miles 68.93	No Charges Available

(1) One-time installation charges are not shown.
(2) This service available only to other communication carriers.
(3) Connection to communication carrier facilities will be at the expense of the communication carr[iers].
(4) Data transmission modems must be supplied by customer (i.e., will incur additional charges).
(5) Mileage charges pertain to local access channels outside of designated local exchange area.

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Table 7-17

es for Satellite Common-Carrier Service (1)

ON TELEGRAPH CO.	AMERICAN SATELLITE CORPORATION	RCA GLOBAL COMMUNICATIONS, INC.
100	105 With C-2 Conditioning +28 With C-4 Conditioning +58	1060 (4) With C-1 Conditioning + 5 With C-4 Conditioning + 19
miles .70 miles .42 miles .38	500 - 1000 miles .66 1000 - 2000 miles .43 2000 - 3000 miles .35	No long-haul mileage charges + 3.30/mi./30mi. (5)
315 ditioning + 5 ditioning +19 ditioning +30	310	1060 (4) With C-1 Conditioning + 5 With C-4 Conditioning + 19
miles .70 miles .42 miles .38	500 - 1000 miles .66 1000 - 2000 miles .43 2000 - 3000 miles .35	No long-haul mileage charges + 3.30/mi./30mi. (5)
Modem nditioning + 5 nditioning +19 nditioning +30	No Charges Available	9675 (4) With C-1 Conditioning + 5 With C-4 Conditioning + 19
miles 7.56 miles 4.55 miles 4.13	500 - 1000 miles 7.92 1000 - 2000 miles 5.16 2000 - 3000 miles 4.20	No long-haul mileage charges + 3.30/mi./30mi. (5)
(2) & (3)	No Charges Available	No Charges Available
miles 6.24 miles 4.29 miles 3.52	500 - 1000 miles 6.36 1000 - 2000 miles 4.08 2000 - 3000 miles 3.60	No Charges Available
(2) & (3)	No Charges Available	No Charges Available
miles 126.05 miles 75.84 miles 68.93	No Charges Available	No Charges Available

cation carriers.
es will be at the expense of the communication carrier.
customer (i.e., will incur additional charges).
nels outside of designated local exchange area.

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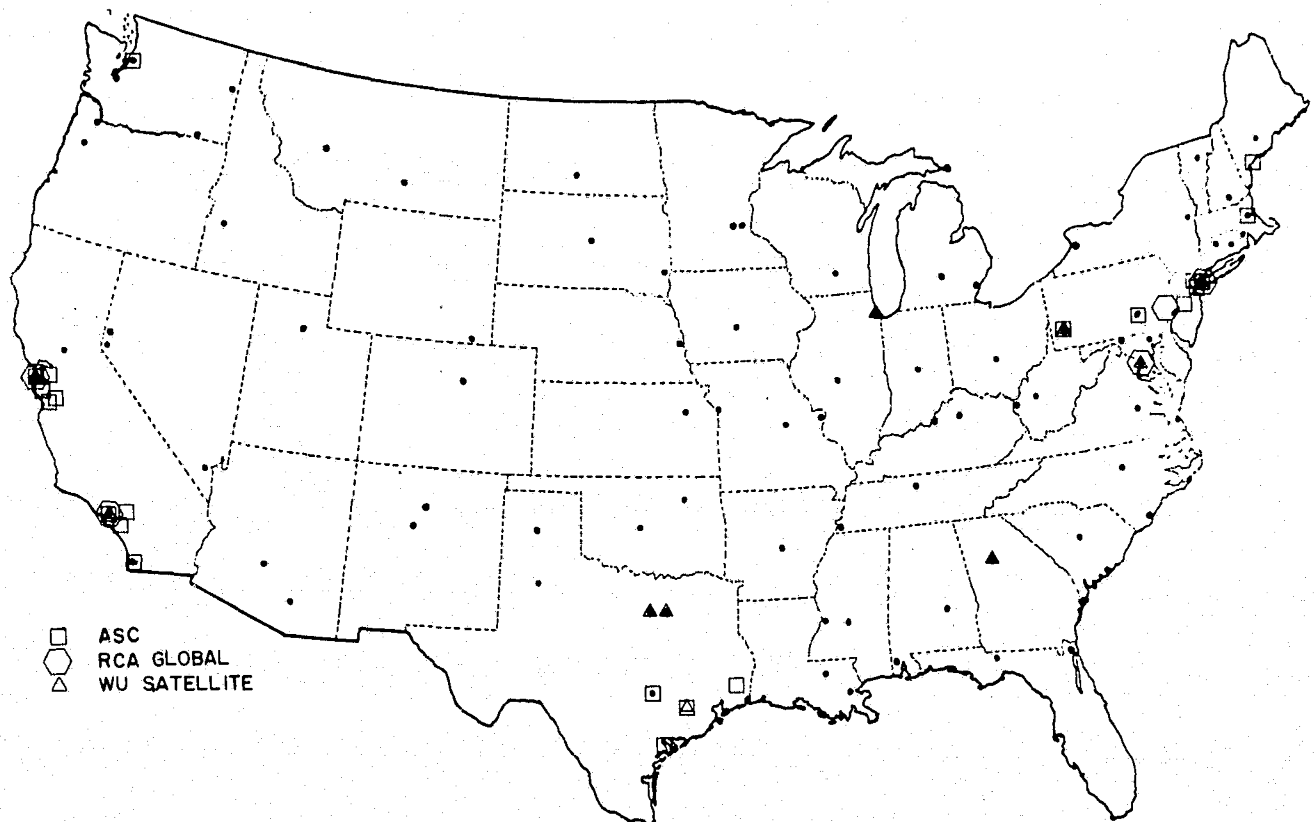

Figure 7-12. Geographical Distribution of Satellite Common-Carrier Service

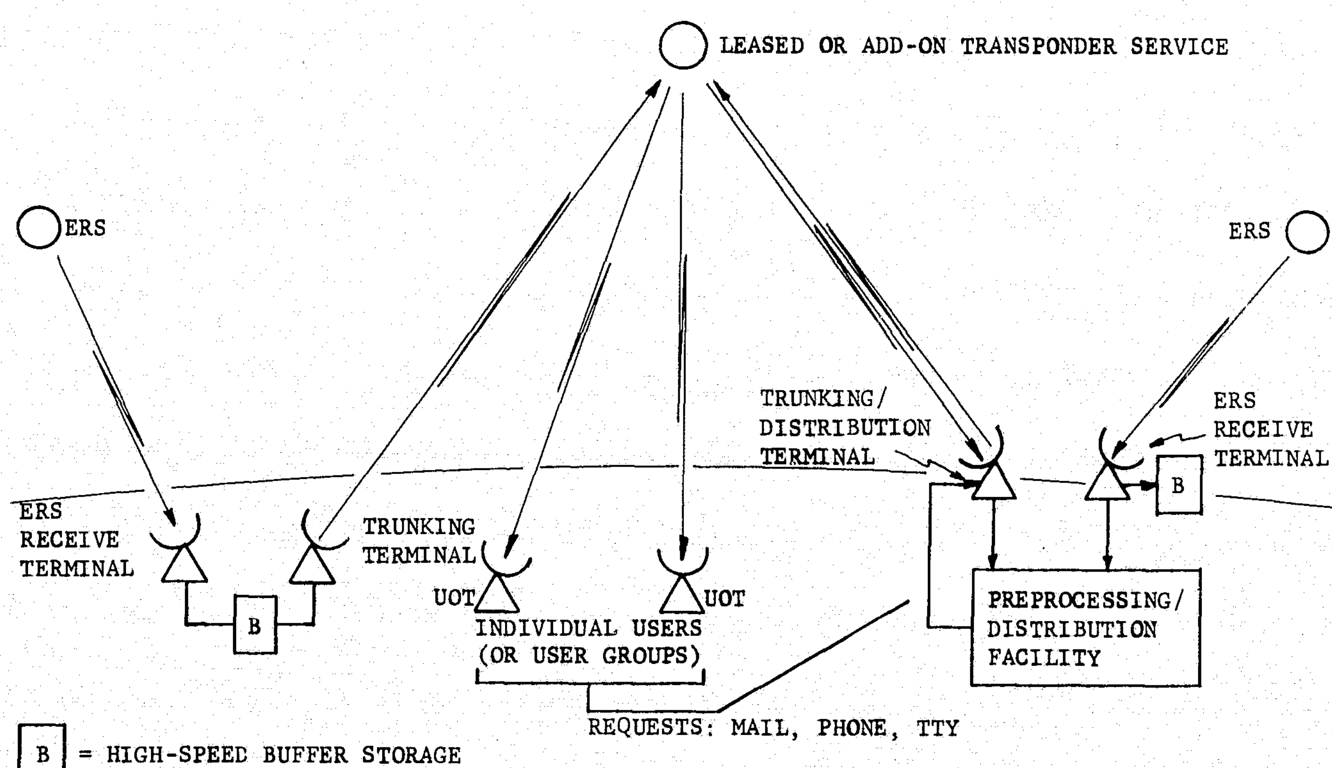

Figure 7-13. System Concept with Leased- or Add-on-Transponder Transmission Alternative

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7.2.2.1 System Cost Equation: If the total cost of the leased-transponder transmission alternative is shared equally among all users, the annual cost per user is given by the following equation:

$$C_u = C_{sy}/n + C_{TT} + C_{ET}(n) \cdot a(k,i) + C_{OM} + C_t \cdot t \qquad (7\text{-}2)$$

where C_{sy} = the annual satellite lease charge

n = the number of users (that is, the number of UOT's)

C_{TT} = the initial installed cost of an up-link data distribution or trunking terminal

$C_{ET}(n)$ = the initial installed cost of a UOT, based on quantity purchases of n units

$a(k,i)$ = the amortization factor for amortization over k years at interest rate i

C_{OM} = the annual cost of operating and maintaining a UOT

C_t = the assessed value of a UOT for tax purposes

t = the equivalent annual tax rate

7.2.2.2 Frequency Considerations: It is clear from the outset that a leased-transponder system can only be competitive with the common carriers if the UOT's are such that they may be located on user premises. Therefore, of the three available frequency bands (C, Ku, and Ka) wherein rain attenuation is not an insurmountable problem at low UOT elevation angles, Ku band appears to be the logical choice. Ku-band operation avoids the C-band RFI problem and the consequent need of terrestrial connecting links, and, by contrast to Ka-band operation, can be expected to be well established by the 1985-1995 time frame and supported with already-developed, "off-the-shelf" hardware. Even supposing off-the-shelf equipment for Ka band, the terminal costs would increase by 15-20% with respect to the Ku-band terminal. For operation at C band, the initial terminal costs would decrease by 10-15%. It should be noted again, however, that operation to C-band users in metropolitan areas would quite likely require an additional terrestrial transmission link. In the following, Ku-band operation is assumed.

7.2.2.3 Annual Lease Charges for Satellite Capacity: All three satellite common carriers presently leasing satellite transmission capacity indicated their annual charge for an entire unprotected 20-MHz, approximately 34-dBW (single-carrier saturated output power) transponder would be close to $1.2M. If protected service is desired, the charge would be $1.4M/year. In all likelihood, these charges will be reduced as the carriers endure the demand uncertainties inherent in initial start-up and are able to assess more precisely their position in the market place and the long-term demand for their service. Some indication of this trend may, indeed, already have occurred. A recent article stated that three WESTAR transponders have been leased to the Public Broadcasting Service at an annual rate of $800K each [7].

Although these transponders are operating at C band, their present lease charges, with a reference of 1976 dollars, are assumed to approximate charges for a Ku-band transponder in the 1985-1995 time frame.

In view of this, two values of annual charge per 40-MHz transponder are used in this study - \$1.2M and \$500K. It is believed that these figures represent likely upper and lower bounds for this variable and, together, provide an assessment of its impact on the annual cost per user.

It is probable that, in an initial system, less than an entire 40-MHz transponder would be required. To estimate the cost for leasing a portion of the available bandwidth and power of the transponder, the following assumptions were made:

- The single-carrier saturated EIRP of a satellite transponder is allocated to a user in direct proportion to the fractional bandwidth of the transponder leased by the user. However, only 80% of the power that is allocated is actually available to the user.

- A user must lease a fraction of the satellite transponder bandwidth that is 20% larger than that actually required to sustain the data rate received by his terminal. This provides for guard bands.

- The cost to the user of leased transponder bandwidth is proportional to the fractional transponder bandwidth leased and to a fractional utilization cost factor, μ. (This factor is shown in the inset of Figure 7-14.)

Given these assumptions, the functional relationship between the required link bandwidth, BW_{req}, and the satellite lease charge, C_{sy}, is shown in Figure 7-14.

7.2.2.4 User-Owned Terminal Cost (C_{ET}): A large investment for the user, one that constitutes, in many cases, a large fraction of the total annual cost per user of the leased-transponder transmission alternative, is the cost of his own receive-only terminal. A simplified block diagram of a UOT is shown in Figure 7-15. It is estimated that, with UOT antenna diameters less than or equal to 5m, no antenna tracking system would be necessary and that, for larger diameters, a simple step-track system would be adequate. Cost estimates for the UOT components are given in Table 7-18. These estimates are single-unit costs for a limited-motion 15' terminal. They do not include development costs. With the thought in mind that the initial system will have only a few users, the QPSK demodulator has been priced for either one or four data rates.

Based on these costs, single-unit UOT initial installed cost was determined as a function of G/T using both the TDA and the paramp front end. The resulting curve is given in Figure 7-16. Details of the calculations are given in Appendix F. The change in UOT cost with G/T is due mainly to a change in antenna cost. Experience has shown that antenna costs will vary in

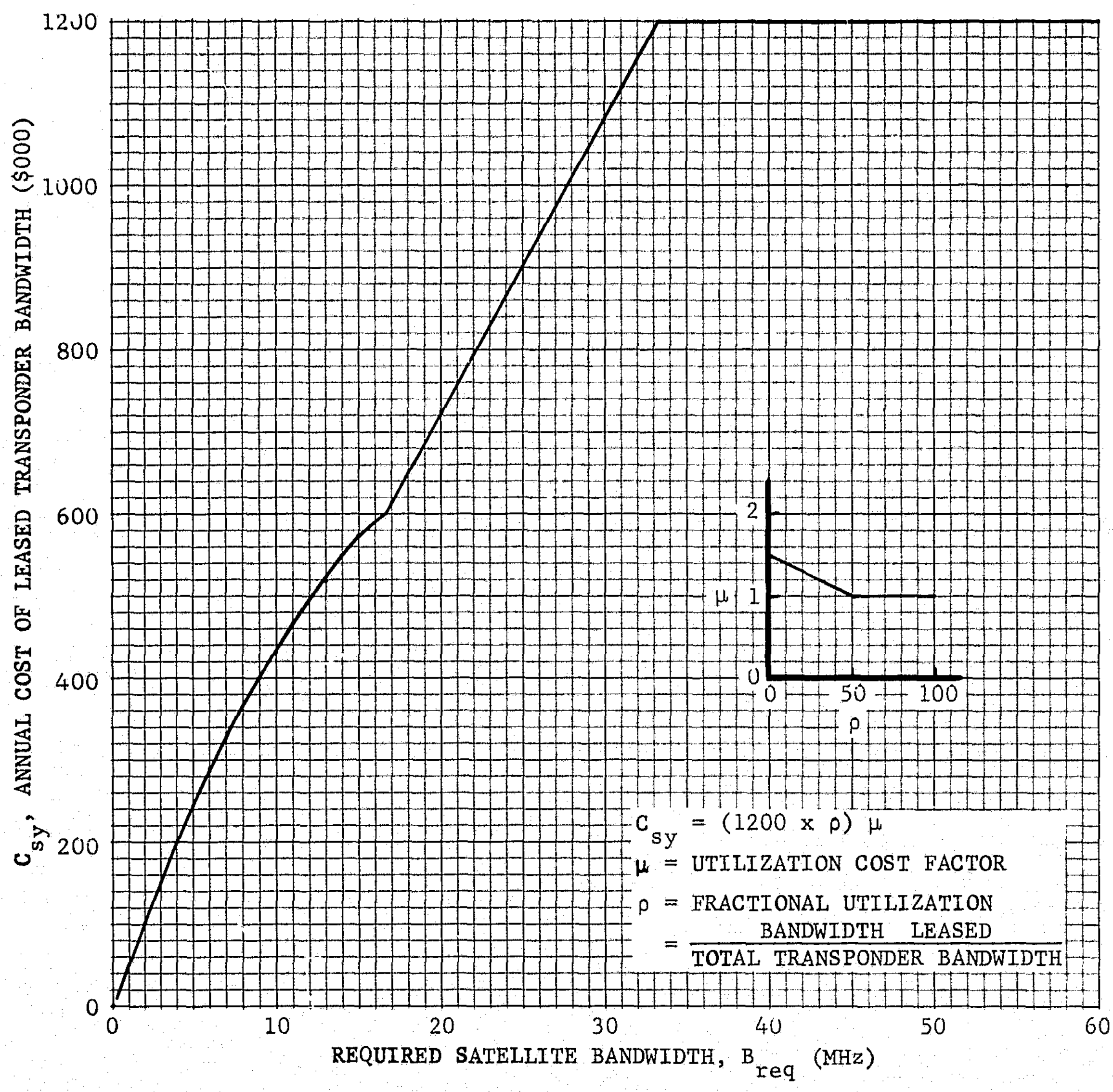

Figure 7-14. Annual Satellite Lease Charge vs. Required Satellite Bandwidth (i.e., not including leased bandwidth that is allocated for guard bands)

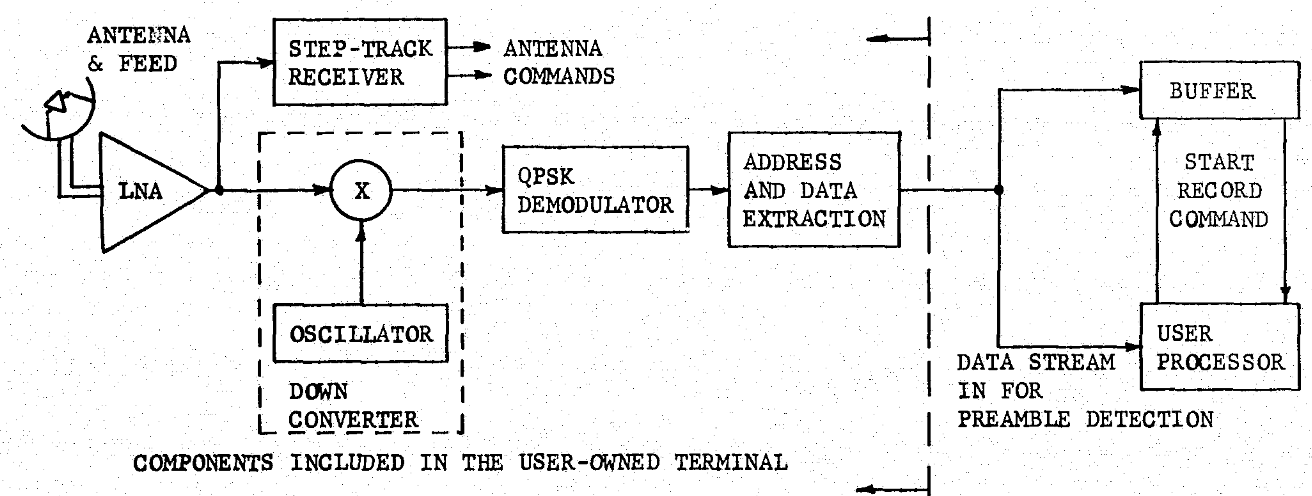

Figure 7-15. Block Diagram of a Receive-Only User-Owned Terminal

Table 7-18

Ku-Band, Receive-Only UOT Component Costs
(Single-unit prices, not including development costs)

COMPONENT	COST ($K)
Antenna System (5m)*	12
Reflector ($6K)	
Feed ($3K)	
Mount ($3K)	
Step-Track System	8
Receiver and Logic ($5K)	
Motors, Gears, Sensors ($3K)	
Low-Noise Preamplifier	
TDA/FET (400°K)	2
Uncooled Paramp (120°K)	18
Down Converter	6
Demodulator, QPSK (four-rate: $18K)	14
Address and Data Extraction Module	20
Miscellaneous	2 - 5
Handling Overhead (10%)**	
Integration, Installation, Test (20%)**	
Profit (10%)**	

* For antenna diameters, D, between 3 and 10 meters, the antenna-system cost, $C_A(D)$, is given by

$$C_A(D) = C_A(5) \cdot (D/5)^{2.2} = \$12K \cdot (D/S)^{2.2}$$

**Percentages apply to all previous items.

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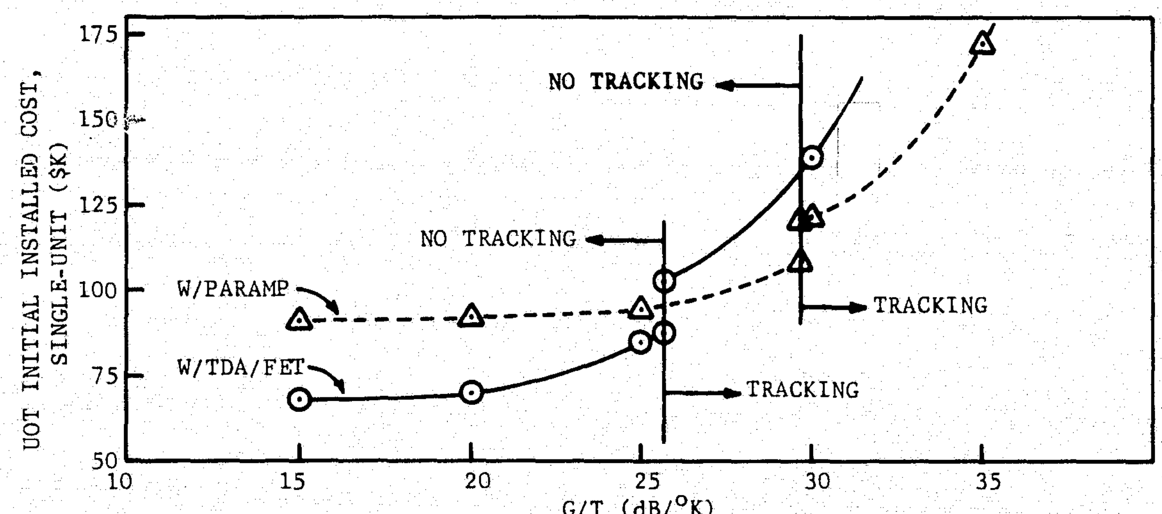


Figure 7-16. The Initial Installed Cost of a Single User-Owned Terminal vs the Terminal G/T. (Cost components from Table 7-18)

proportion to antenna diameter raised to approximately the 2.2 power for antennas in the 3- to 10-meter range.

Earth terminal costs could also be affected by the number of terminals purchased. Were several terminals to be ordered at one time, "assembly-line" methods would likely be introduced into their production. In the theory of cost reduction by assembly-line methods, a "learning curve" approach is generally taken. That is, the cumulative average unit cost of n units is determined as the product of the single-unit cost and a quantity, or cost-reduction, factor, Q(n), given by:*

$$Q(n) = p^{\log_2(n)}$$

where p represents the fraction by which the cost decreases per octave of items produced. The values for p usually range between 0.85 and 0.95. A value of 0.9 is used in this study. The normalized learning curve of quantity procurement (i.e., Q(n) versus n) for p = 0.9 is shown in Figure 7-17.

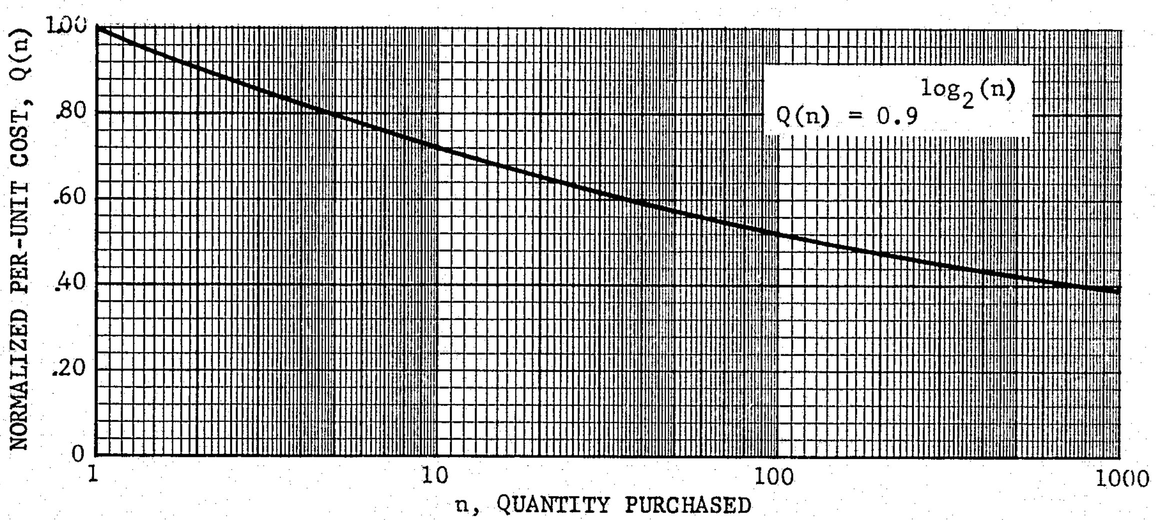


Figure 7-17. The Normalized Learning Curve of Quantity Procurement

* A learning curve is a plot of the cumulative average unit cost for n units versus the number of units.

7.2.2.5 Satellite Total EIRP per Transponder ($EIRP_T$): As shown in Figure 7-16, the cost of a UOT will depend, in large measure, on the required UOT sensitivity or G/T. This, in turn, will depend quite clearly on the total satellite EIRP per transponder ($EIRP_T$). In fact, it is shown in Appendix G that, for 40-MHz transponders,

$$G/T = 69.7 - EIRP_T \quad dB/^{o}K \tag{7-3}$$

It is pertinent, therefore, to indicate the range of values of $EIRP_T$ that may be realistically expected in the 1985-1995 time period.

Three of the satellite corporations mentioned previously (RCA, ASC, WU) are all offering 40-MHz, C-band transponders with about a 34-dBW minimum EIRP over CONUS (Alaska and the lower-48 states). It is possible that Ku-band satellites would offer similar effective radiated power levels per transponder. However, in view of the absence of Ku-band flux density limits (at the surface of the earth) and because of the higher rain attenuation rates at Ku band, it is more likely that a higher value of minimum EIRP will be offered. In fact, current plans for the Ku-band Satellite Business Systems satellite include the use of at least 38 dBW [8]. Were the antenna gain to be more evenly distributed across the field of view or were a 40W instead of a 20W TWT to be used, the minimum EIRP could well be above the 40-dBW level. For this study, values of $EIRP_T$ of 34 dBW and 40 dBW seem appropriate.

7.2.2.6 UOT Sensitivity (G/T): The required UOT G/T can now be determined by substituting the above values of $EIRP_T$ into Eq. (7-3).* The results of this substitution, along with the corresponding UOT antenna diameter and initial installed cost (from Figure 7-16), are given in Table 7-19.

Table 7-19

UOT Required G/T and Associated Cost for Two Values of Satellite EIRP per Transponder ($EIRP_T$)

$EIRP_T$	40 dBW	34 dBW
UOT Required G/T†	29.7 $dB/^{o}K$	35.7 $dB/^{o}K$
UOT Antenna Diameter	5m	10m
UOT Initial Installed Cost	\$109K	\$185K

† Based on $BW_{req} = R_d$. G/T's higher by 1.8 dB would be required if $BW_{req} = 0.667\ R_d$.

* It should be noted that, as determined in Appendix G, the UOT required sensitivity is, as shown in Eq. (7-3), independent of the data rate received by the UOT.

In addition to initial cost, there are two reasons the 5m terminal (40-dBW EIRP per satellite transponder) is preferred. First, it lends itself much more readily to easy, low-cost installation such as on the roof of a user's facility. This type of installation is pictured in Figure 7-18. Second, the 5m antenna would not need to be a tracking antenna, thereby reducing maintenance.

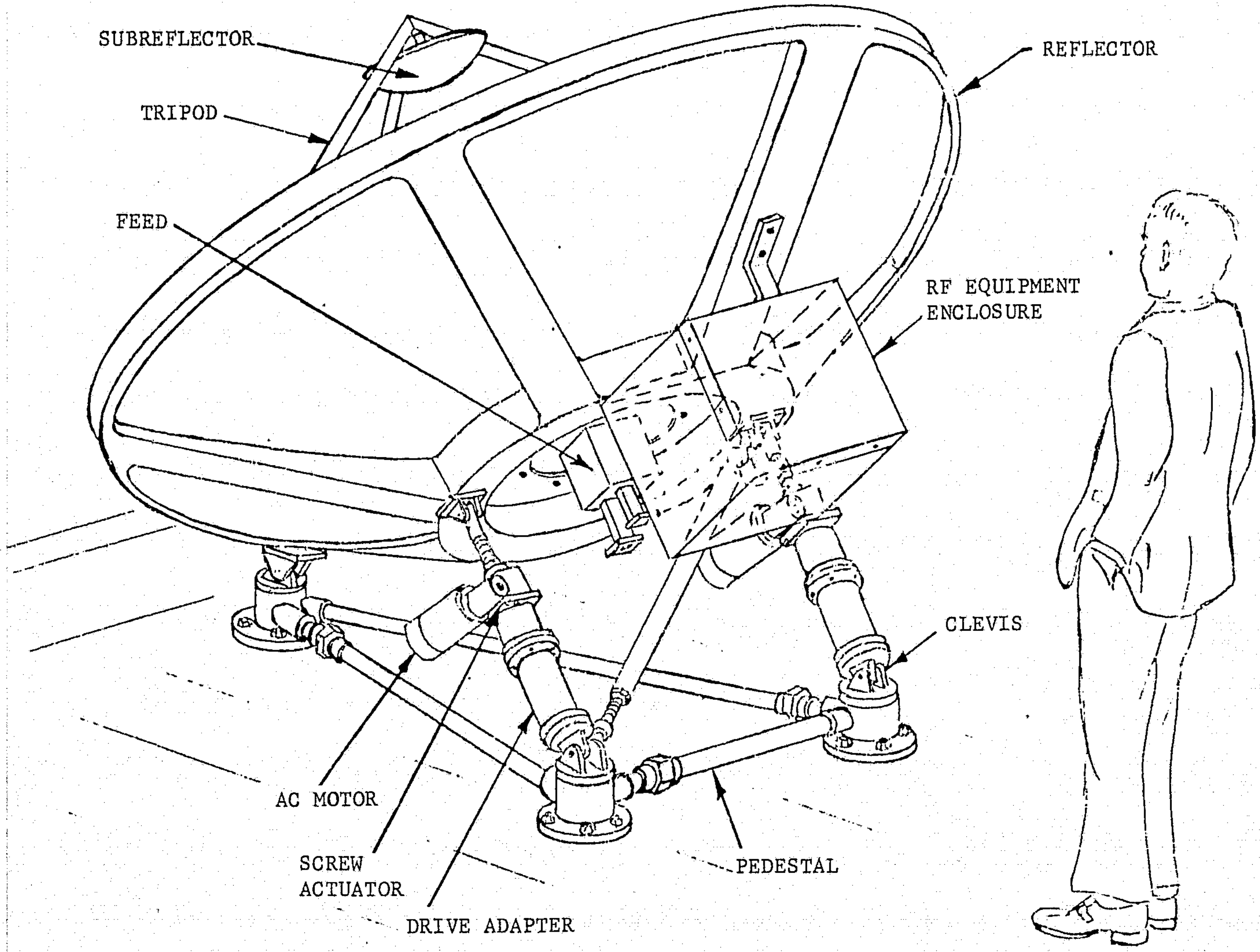


Figure 7-18. Low G/T, Roof-Mounted, Limited Motion, User-Owned Earth Terminal

In conlusion, then, primarily because of the large increase in UOT antenna diameter and secondarily because of the near doubling of the UOT terminal cost that accompanies the use of 34-dBW EIRP transponders, the baseline UOT terminal design in this study is the 5m non-tracking terminal with a G/T of 29.7 dB/^{o}K. The cost of the components of this UOT are, therefore, precisely those given in Table 7-18 (disregarding the entries for the TDA/FET LNA and the step-track system) with $5K for the miscellaneous items.

7.2.2.7 <u>Earth Terminal Operations and Maintenance Costs</u>: The planned receive-only UOT's are intended to be extremely simple and basically self operating. In order to keep the costs for O&M at a minimum, the following O&M strategy is proposed.

1) Terminal operation is to be carried out by non-specialized user personnel and limited to monitoring and recording two or three terminal parameters. These parameters (such as AGC, bit error rate, etc.) would be reported periodically to the maintenance depot.

2) Maintenance would be limited to 4 trips of approximately two days each a year to each site to check out the terminal and perform any required repairs. In addition, any time a terminal failed, repairs would be effected immediately (allow one trip per year).

The estimate of costs for the above operations and maintenance are given in Table 7-20

Table 7-20

Estimated O&M Costs for Receive-Only Terminals

FUNCTION	COST
Operation (performed by on-site personnel)	$0/year
Maintenance	
• Labor and travel - 5 trips ($73/day + $350/trip travel)	$ 2,500
• Parts - 10% of initial terminal equipment costs per year	$ 7,500
TOTAL	$10,000

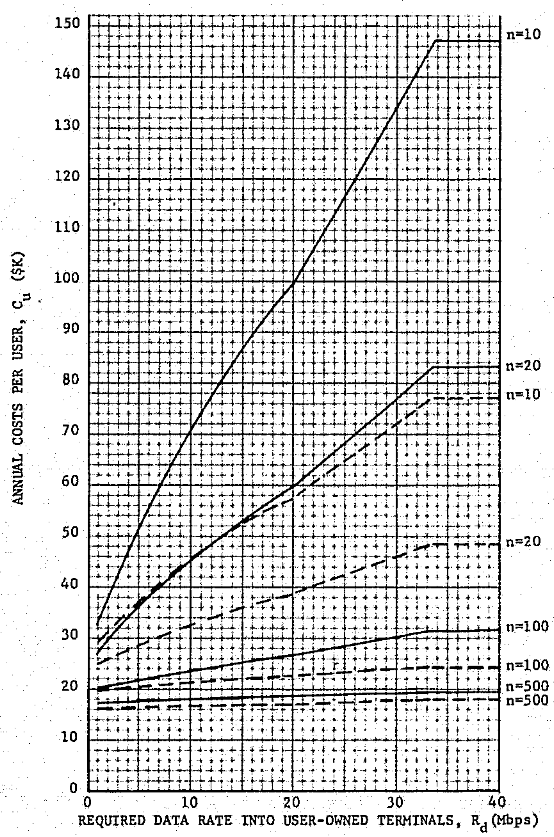
7.2.2.8 <u>User Costs - Leased-Transponder Transmission Alternative (Ku Band)</u>: The annual per-user costs developed here for the leased-transponder alternative will find specific application in Sections 8 and 11 during the cost comparison of candidate data dissemination systems. To determine these annual costs, the subsystem costs given above* were substituted into Eq. (7-2) (Section 7.2.2.1) for the range of values of key system variables shown in Table 7-21. The $500K annual satellite lease cost (per transponder) represents a lower bound to this cost component and provides an assessment of its impact on user costs. The results of the calculations are presented in Figure 7-19 as curves of annual cost per user versus the required data rate into the UOT's. The effect of changes in the other system variables are shown as parametric variations of this curve.

* The cost of the up-link data dissemination or trunking terminal is developed in Section 7.2.2.9.

Table 7-21

Assumed Values of User-Owned-Terminal/Leased-Transponder System Variables

Data rate	R_d	= 1-60 Mbps
Number of UOT's (i.e., users)	n	= 10, 20, 100, 500 -- assumed purchased such that cost reduction may be applied using Q(n)
Satellite EIRP per transponder	$EIRP_T$	= 40 dBW
Frequency	Ku-Band (14.2-GHz up-link; 11.7-GHz down-link)	
Interest rate	i	= 8
Amortization period	k	= 10 years
Annual satellite cost per transponder	C_{ST}	= \$1.2M or \$0.5M for total bandwith & total EIRP
UOT single-unit cost	C_{ET}	= \$109K
Up-link data dissemination terminal single-unit cost	C_{TT}	= \$179K
UOT quantity-purchase cost-reduction factor	Q(n)	$= 0.9^{\log_2 n}$ where n is the number of UOT's purchased
Assessed value of UOT	C_t	$= 0.25\ C_{ET}$
Property tax rate on assessed UOT	t	= 0.125



SATELLITE EIRP PER 40-MHz TRANSPONDER = 40 dBW

C_{ST} = ANNUAL SATELLITE LEASE CHARGES PER TRANSPONDER

C_{ET} = \$109K (INITIAL INSTALLED SINGLE-UNIT COST OF A USER-OWNED TERMINAL)

n = NUMBER OF USER-OWNED TERMINALS IN THE DATA DISSEMINATION NETWORK

———— C_{ST} = \$1.2M

– – – – – C_{ST} = \$500K

Figure 7-19. The Annual Cost per User vs the Required Data Rate into User-Owned Terminals for the Leased-Transponder Transmission Alternative

The curves show that, on high-data-rate links (i.e., links requiring all or nearly all of the transponder bandwidth), annual user costs are very sensitive to both the number of users and the annual transponder lease charges. This was to be expected as charges and satellite costs are shared among only a few users. By contrast, the effect of these two variables on annual per-user cost is much less pronounced at data rates less than 1 Mbps. For example, in Figure 7-19, with a 1-Mbps required data rate, changing the annual cost of the satellite transponder from $500K to $1.2M (an increase of 140%) increases the annual per-user cost by only 12% from $29K to $32.5K, when there are ten users. The increase in user cost is even smaller with more users in the network.

7.2.2.9 <u>Cost of Trunking Link ET's</u>: The cost of earth terminals for trunking of raw or preprocessed data will be slightly higher than that of the single-user or area-center UOT's described earlier. This cost increase arises from a need for a frequency generator, a modulator, an up converter, and a high-power amplifier (HPA) for the up-link; and a desire to have redundant preamplifiers for the down-link.

It will be assumed that the equipment costs and the system costs incident to the installation of a trunking earth terminal are as shown in Table 7-22. The initial installed cost of $179K shown there converts to an equivalent annual cost per terminal of $43.0K. The conversion is shown in equation form as follows (assuming that these terminals are unattended):

$$\overbrace{\$179\text{K}}^{\text{initial installed cost}} \times \underbrace{0.149}_{\substack{\text{amortization of}\\ \text{initial cost over}\\ \text{10 years, @ 8\% interest}}} + \underbrace{(\$4\text{K} + \$123 \times 0.10)}_{\substack{\text{annual maintenance}\\ \text{cost}}} = \$43.0\text{K}$$

Table 7-22

Trunking-Link Earth-Terminal Equipment Costs
($G/T = 29.7$ dB/$^{\circ}$K)

5m antenna (limited motion)	$ 12K
500W* HPA (transmitter + power supply)	40K
Frequency generator, modulator and up converter	10K
Paramp (uncooled), dual	36K
Down Converter	6K
Demodulator (1 rate)	14K
Miscellaneous hardware	5K
TOTAL EQUIPMENT COST	$123K
Handling overhead (10%)**	12.3K
Integration, installation, test (20%)**	27.1K
Profit (10%)**	16.2K
INITIAL INSTALLED COST	$178.6K

* Link budget is given in Appendix G.

** Percentages apply to all previous entries.

7.2.2.10 Trunking Link Costs: The annual cost of a raw- or preprocessed-data trunking link will depend on the required link capacity in much the same way as does the annual cost of user-data distribution links discussed in previous sections. That is, the cost of the trunking terminal, itself, is essentially fixed, the link cost then rising or falling according to the fraction of the transponder needed to support the link capacity. Assuming that the satellite charges are as given in Section 7.2.2.1 and that the required satellite bandwidth -- as defined in assumption 1 of Section 7.2.2.1 -- is equal to the link data rate, the annual cost of a trunking link as a function of link data rate is given in Figure 7-20.

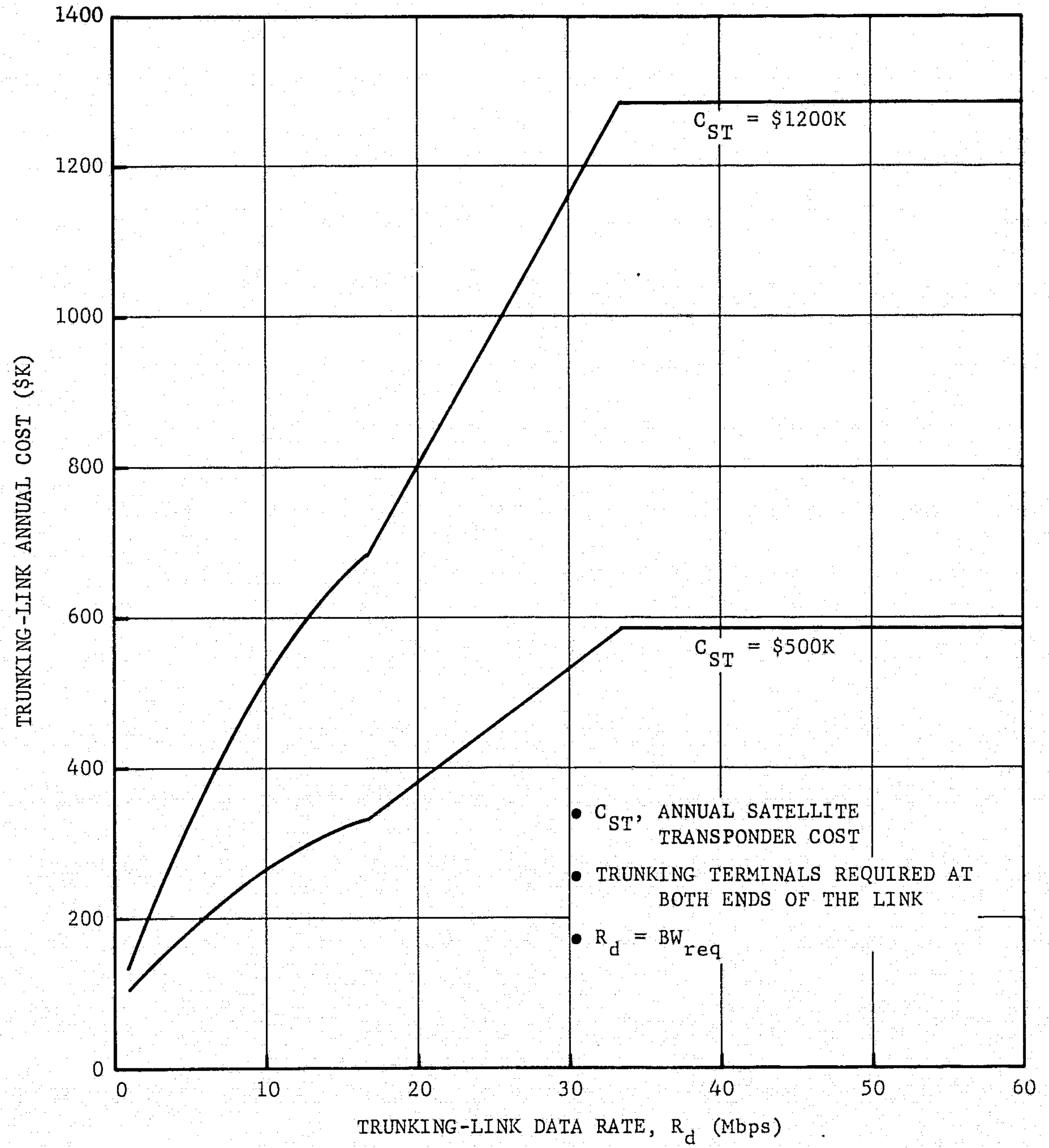


Figure 7-20. Annual Cost of Trunking Link vs. Trunking-Link Data Rate for Leased-Transponder Transmission Alternative

7.2.3 <u>Add-On Transponder Transmission Alternative</u>: An attractive alternative to leasing satellite capacity from commercial carriers is the addition of a communication transponder to a government-sponsored geo-synchronous satellite such as SEOS. The cost breakdown for a single add-on transponder with and without redundancy for C, Ku, and Ka band are given in this section. Both the recurring and the non-recurring costs are fairly straightforward, being derived from existing programs. For this alternative, it is the cost/performance impact on the host spacecraft which is difficult to determine.

If the host spacecraft were an earth-resources applications satellite such as SEOS, it would be in the direct interest of the earth-resources program office to minimize costs to users and, thus, to promote the add-on system. The cost might be absorbed in the general program funding; i.e., not broken out and passed on to the user. A similar situation may arise if the transponder were added to a second-generation synchronous meteorological satellite where the communications capability might be shared with meteorological data dissemination services. In either case, the cost to users of the add-on transponder should be minimal. However, if the transponder were added to, for instance, another communication satellite, then the costs of the satellite and launch would probably be shared by the earth-resources program office in proportion to the fraction of the total satellite power and weight required by the add-on transponder.

For this study, it is assumed that the transponder is added to SEOS and the costs associated with the transponder are only for its development, fabrication, and integration on SEOS. No charges for the host satellite's power and upkeep are assumed. Tables 7-23 and 7-24 detail the cost breakdown for single-thread, no-redundancy transponders at C, Ku, and Ka bands. Redundancy would double the cost of the TWTA and add about 30% to the electronics. The major cost for a transponder is the development or non-recurring cost. If an existing design can be used, which was assumed for the C- and Ka-band transponders,* the total cost can be reduced to 1/2 of the cost required to develop an all-new transponder. In either case, the resulting transponder would probably be similar in appearance to the C- and Ka-band transponders of the Japanese CS satellite, simplified block diagrams of which are shown in Figures 7-21 and 7-22.

The total cost of an add-on transponder for various combinations of off-the-shelf and no-prior-development items can be obtained by combining the costs shown in Tables 7-23 and 7-24. For Ku-band operation (chosen for essentially the same reasons as given in Section 7.2.2.2 for the leased-transponder transmission alternative), combining these costs according to the following assumptions leads to a value of $800K for the installed (i.e., integrated, in-orbit) cost of the transponder.

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* For C and Ka band, Aeronutronic Ford has an existing design from the Japanese Communication Satellite (CS) program.

Table 7-23

Costs for an Add-On Transponder (not including antenna) ($K)

BAND/POWER	NONRECURRING		RECURRING		SUBTOTAL	SOURCE
	ELECTRONICS	TWTA	ELECTRONICS	TWTA		
C (4 WATTS)	-	-	70-100*	40-50	110-150	CS
Ku (5-10 WATTS)	400-500	50-70	90-120	55-65	600-755	
Ka	-	-	120-140*	70-90	190-220	CS

* Represent costs for integration, fabrication, and test for a single transponder from the Japanese CS program.

Table 7-24

Antenna Costs for an Add-On Transponder ($K)

TYPE	NONRECURRING	RECURRING	SUBTOTAL
Spot Beam	120-150	80-90	200-240
Shaped Beam (CONUS + Alaska)	250-300	100-115	350-415

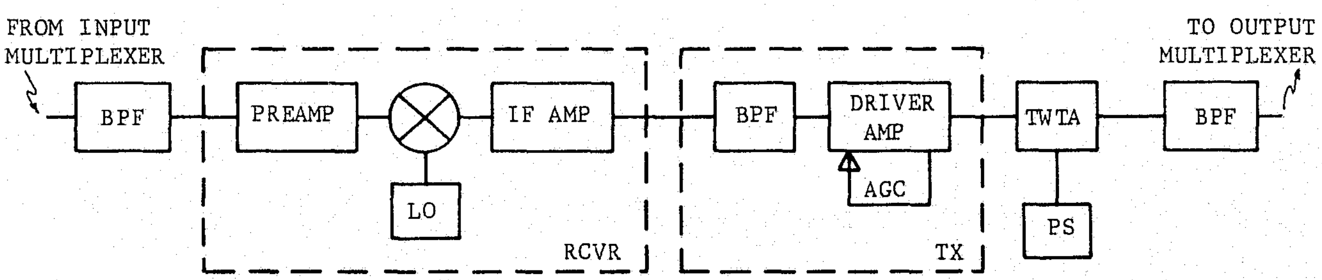

Figure 7-21. Block Diagram of Japanese Communications Satellite (CS) C-Band Transponder

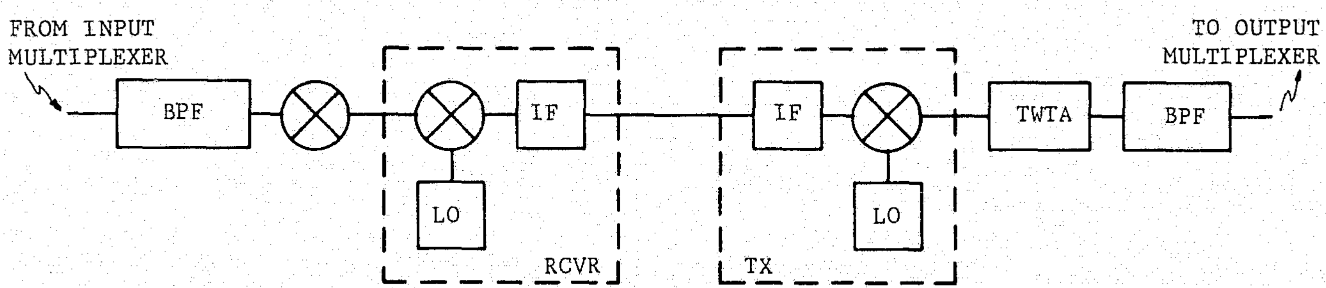

Figure 7-22. Block Diagram of Japanese Communications Satellite (CS) Ka-Band Transponder

- Ku-band operation
- In the 1985-1995 time frame, 5- and 20-watt TWTA's will have comparable costs.

• Transponder electronics and TWTA are off-the-shelf designs	\$105.0K
	60.0K
• Cost of redundant electronics for transponder is equal to 30% of the recurring electronics cost.	31.5K
• Add the cost of one additional TWTA	60.0K
• Antenna costs are for a shaped beam including development	382.5K
	\$639.0K
• Integration costs onto the host satellite will represent an additional 25% of the total costs above.	x 1.25
	\$798.75K

To assess the total cost per user of data distribution for a UOT/add-on transponder system, Eq. (7-2) was modified to reflect an initial investment rather than an annual lease charge for the cost of the satellite segment. It was also assumed that the full cost of the add-on transponder would be shared equally among the users of earth-resources data (i.e., that there would be no mission for the transponder by which revenue could be generated other than that of earth-resources data dissemination), and that the full power of the transponder would be used to reduce the required UOT G/T as a function of data rate. The resulting equation is

$$C_u = \frac{C_{XP} * a(k,i)}{n} + C_{TT} + C_{ET}(R_d,n) * a(k,i) + C_{om} + C_t * t \qquad (7\text{-}4)$$

where C_{XP} is the initial cost of the add-on transponder, $C_{ET}(R_d,n)$ shows that the cost of a UOT is now a function of data rate, R_d, as well as of the number of terminals, and the other variables are as defined for Eq. (7-2).

With Eq. (7-4)*, the annual cost per user was determined for the UOT/add-on transponder system as a function of the required data rate. This cost is shown in Figure 7-23 for 10-500 users. The amortization period of 10 years, an 8% interest rate, 25% assessed tax value, and 12.5% tax rate on assessed tax value were the same as used in the leased-transponder system calculations. The effect on annual user costs of doubling the initial transponder cost from \$800K to \$1.6M is shown in Figure 7-24.

Comparing the costs shown in these two figures with those of Figure 7-19, the add-on-transponder alternative has a considerable cost advantage over the leased-transponder alternative when high data rates are required and there are relatively few (say, less than 50) users of the system. However, at the lower data rates (less than 2 or 3 Mbps), the cost effectiveness of the add-on-transponder alternative is rather independent of the number of users and will depend, instead, on the initial cost of the add-on transponder.

* $C_{ET}(R_d,n)$ values used in generating Figures 7-23 and 7-24 are given in Table F-3.

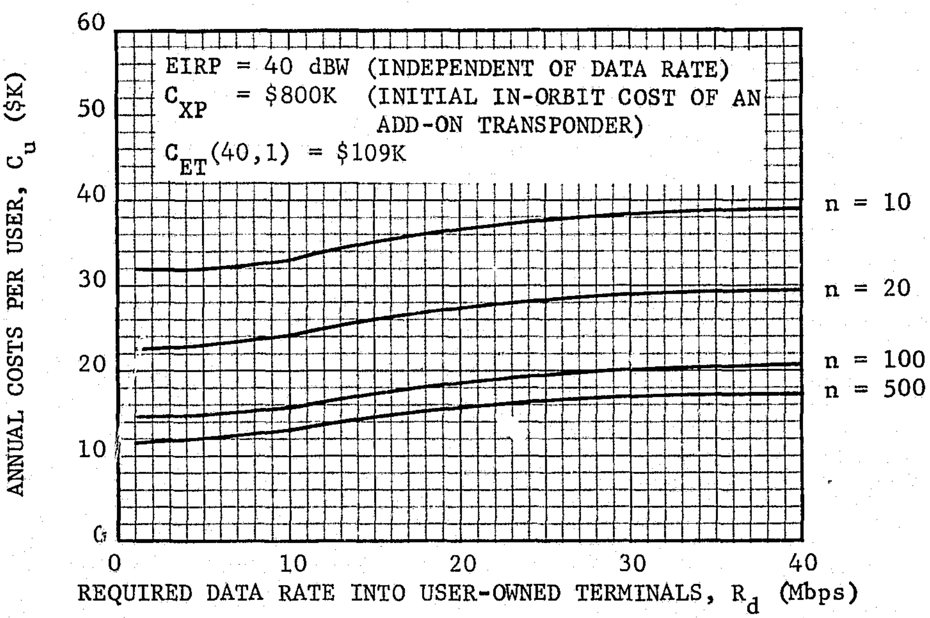

Figure 7-23. The Annual Cost per User vs. the Required Data Rate into User-Owned Terminals for the Add-On Transponder Data Transmission Alternative

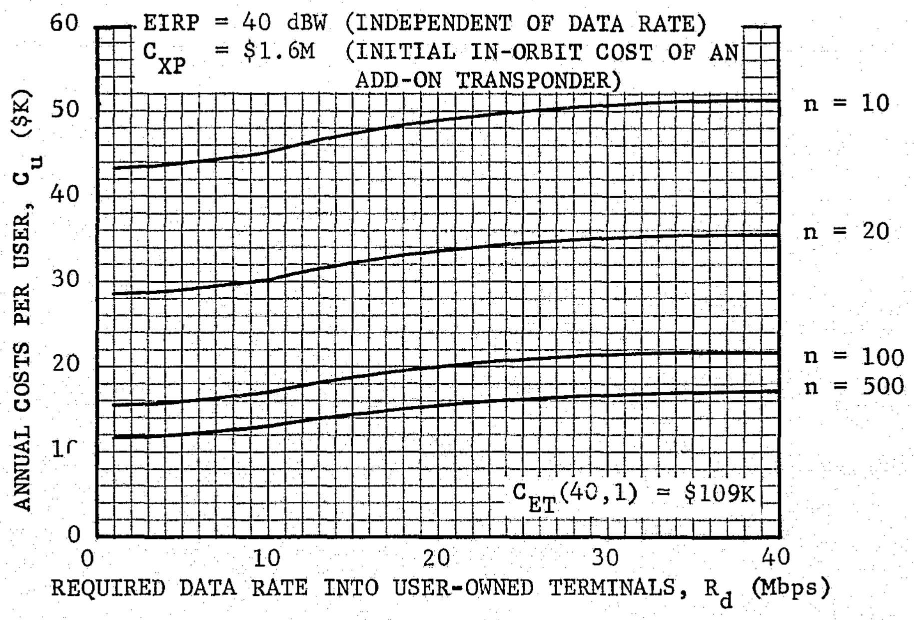

Figure 7-24. The Annual Cost per User vs. the Required Data Rate into User-Owned Terminals for the Add-On Transponder Data Transmission Alternative

7.2.4 Impact of UOT Costs: In previous sections, the impact on user costs of cost changes in the space segment of the leased-transponder and the add-on-transponder systems were determined. A common element for user data dissemination in both systems is the user-owned receive-only ET. In this section, we assess the influence cost reductions in UOT equipment will have on user costs.

The three major cost items shown in Table 7-19, Receive-Only UOT Component Costs, are the paramp, the QPSK demodulator, and the address and data-extraction module. Significant development of these items will result in lowered costs for the earth terminal. The following assumptions were made for the purpose of evaluating the sensitivity of user costs to UOT initial costs.

- In the future, system temperatures nearly equivalent to those of today's uncooled paramps will be achieved using solid-state devices and thermoelectric cooling. This will be done at a cost equaling that of present-day TDA LNAs.

- Modem costs will be reduced through the use of multiple high-speed microprocessors. A cost of $5K is assumed for the demodulator.

- Similar cost-reduction techniques will bring the cost of the address and data-extraction module down to $10K.

These assumptions represent a reduction in UOT initial installed cost of $51K, from $109K to $58K, as shown in Table 7-25.* New annual per-user costs were computed with this reduced cost and are given, as functions of the number of users, in Figure 7-25 and in Figures 7-26** and 7-27** for the leased- and the add-on-transponder systems, respectively. The annual maintenance cost is now reduced from $10,000 to $6,500 due to the lower cost of replacement parts.

Comparing these figures with Figures 7-19, 7-23, and 7-24, it may be seen that the reduced-cost UOT reduces the annual user costs by from $5K to $10K, depending on the data rate. Although savings of this magnitude are not very dramatic in the cases involving high data rates and small numbers of users, for some of the lower-data-rate cases it amounts to a nearly 40% drop in overall per-user annual cost.

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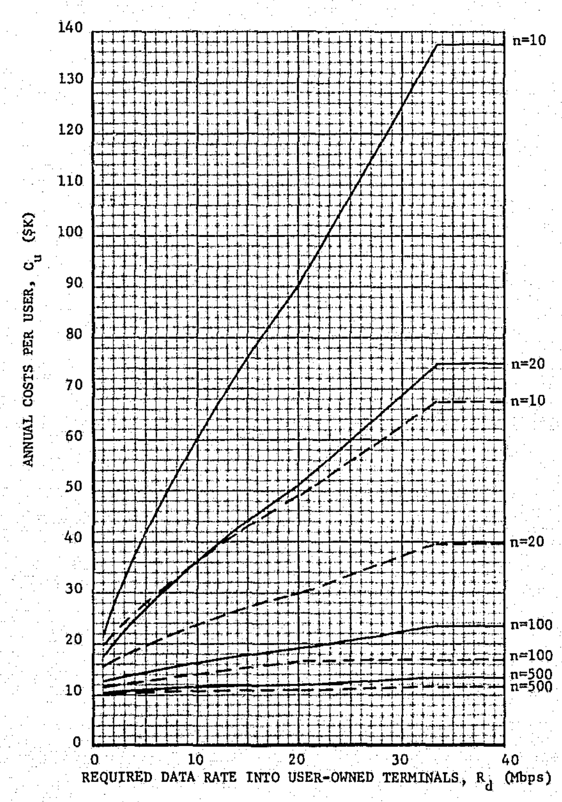
* Even with these assumed cost reductions in terminal equipment, these terminals ($40K total equipment cost) are still expensive compared to the cost of a Communications Technology Satellite terminal ($10K total equipment cost). [9]

** $C_{ET}(R_d,n)$ values used in generating these figures are given in Table F-4.

Table 7-25

The Initial Installed Cost of a UOT with Reduced-Cost Components

COMPONENT	COST ($K)
Antenna System (5m) (Reflector, Feed, Mount)	$12.0
Low-Noise Preamplifier (Uncooled Paramp, 120°K)	2.0
Down Converter	6.0
Demodulator, QPSK	5.0
Address and Data Extraction Module	10.0
Miscellaneous	5.0
TOTAL EQUIPMENT COST	$40.0
Handling Overhead (10%)	4.0
Sub-total	$44.0
Integration, Installation, Test (20%)	8.8
Sub-total	$52.8
Profit (10%)	5.3
INITIAL INSTALLED UOT COST	$58.1



SATELLITE EIRP PER 40-MHz TRANSPONDER = 40 dBW

C_{ST} = ANNUAL SATELLITE LEASE CHARGES PER TRANSPONDER

C_{ET} = $ 58K (INITIAL INSTALLED SINGLE-UNIT COST OF A USER-OWNED TERMINAL)

n = NUMBER OF USER-OWNED TERMINALS IN THE DATA DISSEMINATION NETWORK

———— C_{ST} = $1.2M

– – – – – C_{ST} + $500K

Figure 7-25. The Annual Cost per User vs. the Required Data Rate into User-Owned Terminals for the Leased-Transponder Data Transmission Alternative

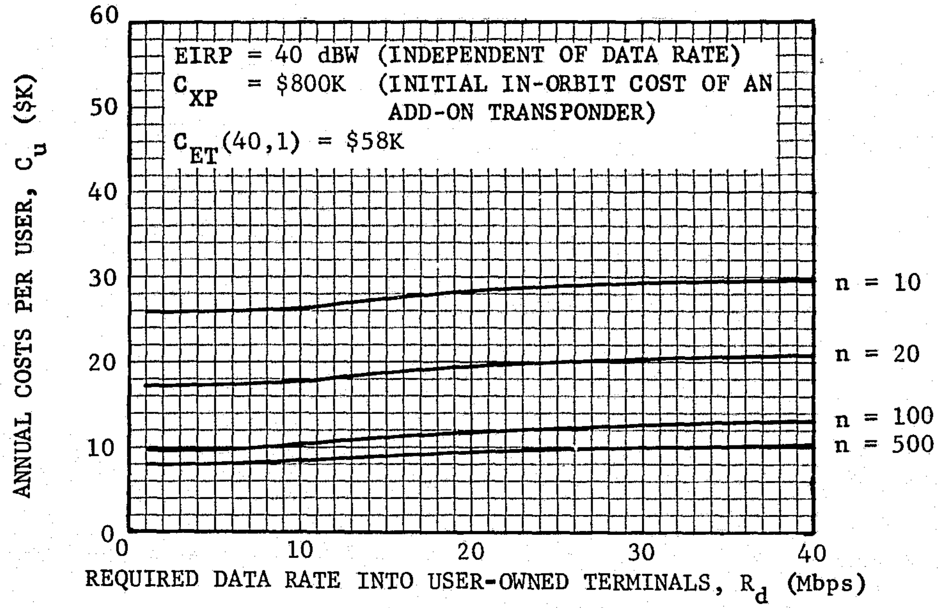


Figure 7-26. The Annual Cost per User vs. the Required Data Rate into User-Owned Terminals for the Add-On-Transponder Data Transmission Alternative

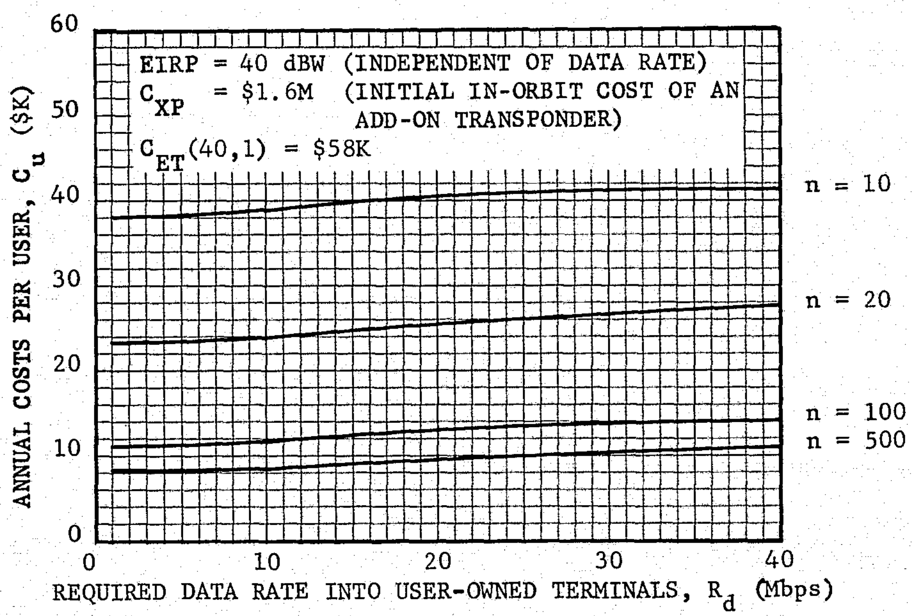


Figure 7-27. The Annual Cost per User vs. the Required Data Rate into User-Owned Terminals for the Add-On-Transponder Data Transmission Alternative

7.2.5 Low-Orbit Earth-Resources Satellite (LERS): With the addition of a communication transponder to a LANDSAT satellite or other LERS, it is possible to both trunk raw or preprocessed data and distribute user data during periods of mutual LERS visibility among the affected earth locations. However, it will be seen quickly that this scheme increases trunking-terminal and user-owned-terminal costs significantly and imposes restrictions on the location(s) of the preprocessing/distribution center(s) beyond those applicable were a synchronous communication transponder to be used.

7.2.5.1 User Data Distribution via LERS: The high UCT cost arises from the requirement that it provide fully automatic tracking and full-motion capabilities. In addition, the very limited time available for transmission (when both the central distribution terminal and the user terminal are in view of the LERS) forces the UOT to receive at data rates approaching those of the raw-data link down from the LERS sensors (about 102 Mbps for the 30m/7-band multi-spectral scanner). This type of UOT is very different from that proposed in Section 7.2.2.2. Indeed, the installed cost of a UOT, with LERS data distribution, would approximate that of a raw-data terminal which is being estimated at $485K, for the rf-to-demodulation equipment only ($335 + 10% handling; 20% integration, installation, and test; and 10% profit -- see Table 7-13). Clearly, this user-data transmission alternative is not cost effective.

7.2.5.2 Data Trunking via LERS: Data trunking could be required on any of the links shown in Table 7-26. Some of the links may be ruled out because the periods of mutual visibility between the end points are either non-existent or are too short to support the link with economically viable data rates. This is the case for links between Fairbanks and any of the three lower-48-state locations and for links between Goldstone and Greenbelt, especially with the ERS at 710 km, as may be seen from Figures 7-28 and 7-29. LERS trunking links between Goldstone or Greenbelt and Sioux Falls could be supported but would require one primary, or raw-data reception, terminal at Sioux Falls for each LERS in use, in addition to the primary terminals at Goldstone and Greenbelt. This arrangement is costly and is not necessary since a single primary terminal at Sioux Falls has adequate visibility from the LERS to receive all the data directly.

Table 7-26

Possible Trunking-Link End-Point Locations in a Data Dissemination Network

Fairbanks, AK	and	Sioux Falls, SD
Fairbanks, AK	and	Greenbelt, MD
Goldstone, CA	and	Greenbelt, MD
Goldstone, CA	and	Sioux Falls, SD
Sioux Falls, SD	and	Greenbelt, MD
White Sands, NM	and	Sioux Falls, SD
White Sands, NM	and	Greenbelt, MD

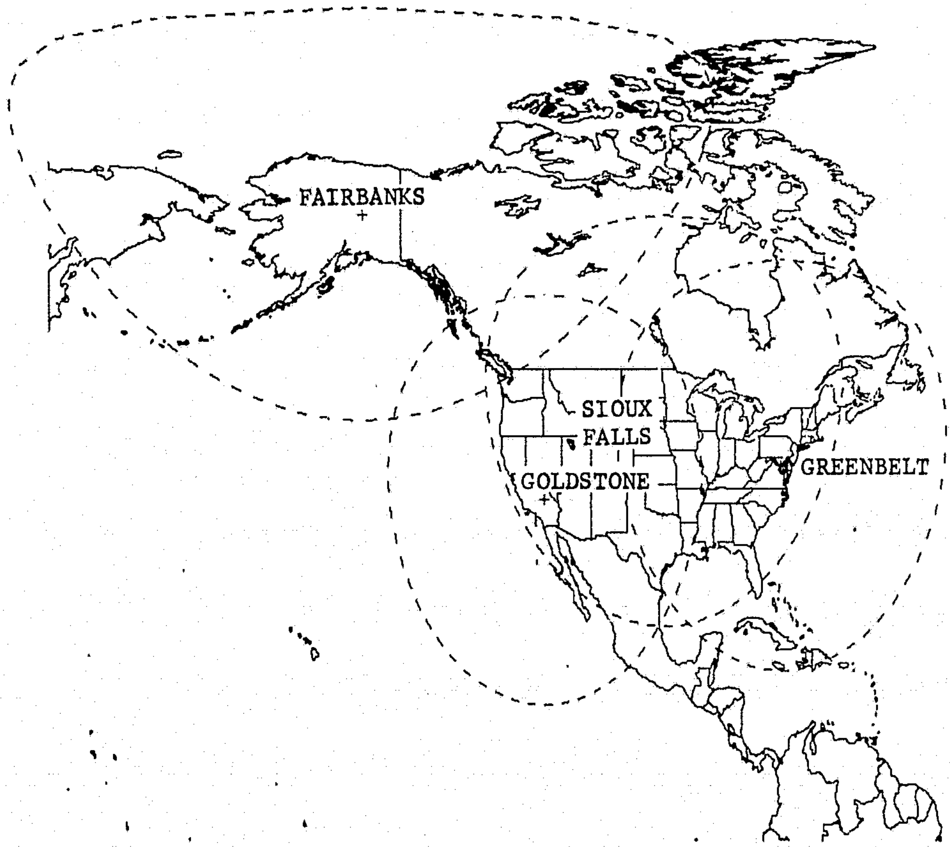


Figure 7-28. Site Coverage Contours for 5° ET Antenna Elevation Angle and LERS Altitude of 710 km

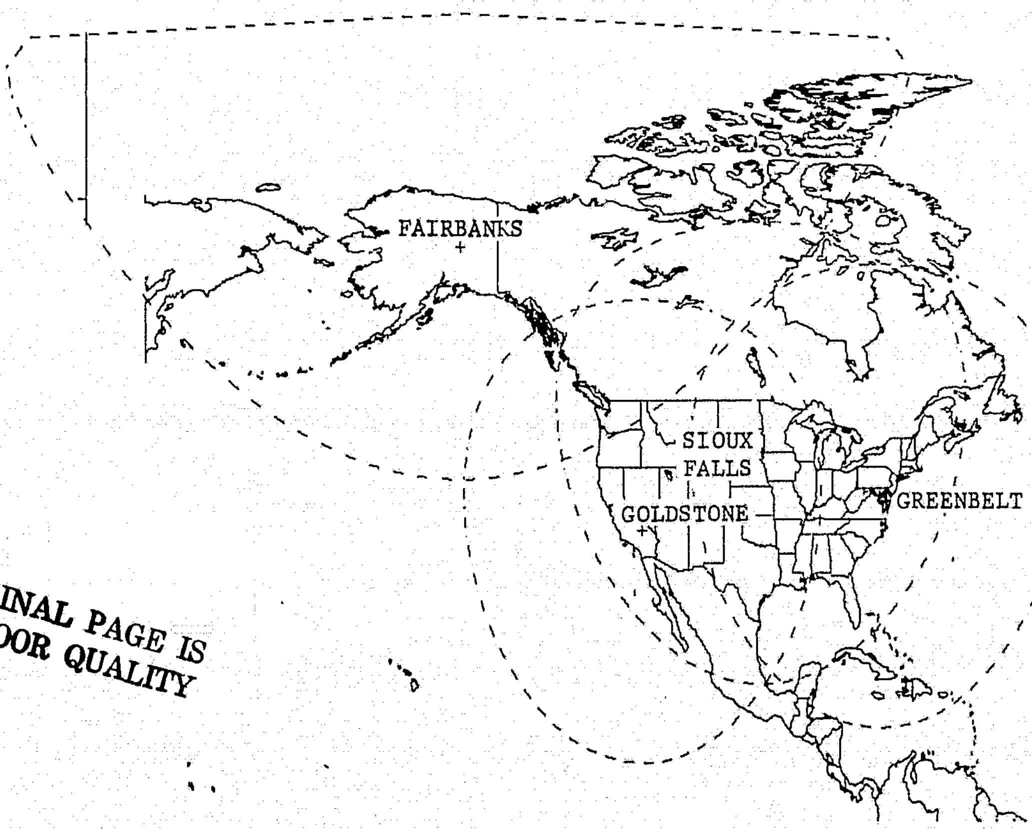


Figure 7-29. Site Coverage Contours for 5° ET Antenna Elevation Angle and LERS Altitude of 900 km

A raw-data trunking link from White Sands to Sioux Falls or to Greenbelt for preprocessing could be necessary in the event that the raw data were relayed into White Sands via the TDRS. In this case, however, use of the LERS for trunking would force construction of either two or three otherwise completely unnecessary primary terminals.

In any of the above trunking arrangements, a communications transponder and associated support systems would first need to be installed on the LERS. Its cost would be roughly comparable to that of adding a transponder to a synchronous satellite. In view, therefore, of the substantial cost of additional primary ET's (as compared to the cost of Domsat-type ET's) to establish those LERS links that are even possible, it may be concluded that, from the standpoint of cost, this alternative need not be considered further.

7.2.6 Microwave LOS Transmission Alternative: The costs of terrestrial LOS microwave equipment are given in Table 7-27. They are estimates based on the average costs of similar turn-key facilities [10,11,12]. With these estimates, a smooth curve has been constructed in Figure 7-30 to show equivalent annual cost versus link length of an LOS link assuming adjacent repeaters are spaced 30 miles apart. It is apparent that the LOS alternative would not be cost effective except on relatively short, very high data-rate links.

Table 7-27

Microwave (LOS) Equipment Costs

EQUIPMENT	COST ($K)	
	TERMINAL*	REPEATER
2 rf Channels (Redundant)	$10.0	$19.0
Antenna(s) and Feed(s)	2.5	5.0
Batteries and Charger	2.0	2.5
Tower	-	7.0
Miscellaneous	1.5	2.5
Installation and Test (~20%)	3.0	7.0
Power		10.0
Land and Improvements		10.0
Shelter		6.0
Engineering and Initial Spare Parts	4.0	7.5
INITIAL INSTALLED COST, C_I	$23.0	$76.5
Equivalent Annual Cost $C_I * [(1/6.7)^{**} + 0.2^{***}]$	8.0	26.7
Installed Cost of Additional rf Channel	5.0	10.0

* Located on user premises.

** Amortization of initial capital cost over 10 years at 8% interest.

*** Annual operations and maintenance cost (20% of C_I).

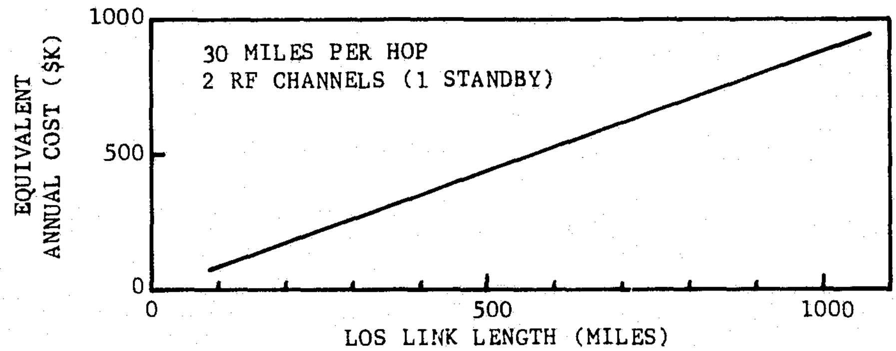


Figure 7-30. Equivalent Annual Cost vs Link Length of Terrestrial Microwave LOS Facility

7.2.7 Summary of Systems for Transmission between Two Earth Locations: Data has been presented, principally in the form of curves, that can be used to support cost comparisons among the alternative transmission systems. Summary comments regarding each alternative are offered in Table 7-28. Comparison of the transmission alternatives is contained in Section 8 and is followed in Section 11 by comparisons of complete data dissemination network configurations.

Table 7-28

Transmission Alternatives - Summary Comments

TRANSMISSION ALTERNATIVES	SUMMARY COMMENTS*	
	TRUNKING LINKS	USER DATA LINKS
Common Carrier		
Satellite	• Probably available • Not least cost • Very flexible, if available	• Not always available • Least cost only for short, low-data-rate links • Very flexible
Landline	• Probably available • Not least cost • Very flexible, if available	• Always available • Not least cost except for short, low-data-rate links • Very flexible
Leased Transponder	• Available • Not least cost if add-on transponder available • Moderately flexible	• Available • Next to add-on system in cost for most links • Flexible
Add-on Transponder	• Probably not available • Least cost • Moderately flexible	• Probably not available • Least cost for most links • Flexible
LERS	• Probably not available • Very high cost • Moderately inflexible	• Probably not available • Extremely high cost • Moderately flexible
LOS Microwave	• Available • Very high cost • Inflexible	• Available • Extremely high cost • Inflexible

* Flexibility is with regard to the relative ease and cost of relocating the end points of any particular link.

SECTION 8.0

PRELIMINARY SELECTION OF TRANSMISSION ALTERNATIVES

8.1 Introduction.

Several combinations of network topologies and data transmission alternatives may be envisioned to accomplish dissemination (collection and distribution) of earth-resources data generated by low-orbit satellites. The purpose of this section is to describe the topologies and the various links within each topology by generic category and then to compare the costs of the various electronic data transmission alternatives* that may be used within each link category. The more costly transmission alternatives are then eliminated from further consideration.

8.2 Network Topologies & Transmission Links.

A network topology is defined as the physical layout of a network. Topologies may be classified according to whether they incorporate regional or central raw-data reception and whether they incorporate regional or central data preprocessing and distribution. For this study, three generic classes of topology are being considered: 1) regional reception with regional preprocessing and distribution, 2) regional reception with central preprocessing and distribution, and 3) central reception with central preprocessing and distribution. Within each generic class, two sub-classes exist. The data may be transmitted from the preprocessor directly to the user, or it may be transmitted to the user via an intermediate data distribution hub, herein called an agency area center. Illustrative diagrams of these topologies are shown in Figure 8-1.

The various transmission links represented or implied in the topology diagrams are: 1) trunking links -- links from the primary earth terminals to the central preprocessor or the link from the central preprocessor to the central distributor, 2) area input links -- links from the central or regional distributors to the area centers, 3) direct-to-user links -- links from the central or regional distributors direct to the users, and 4) area-to-user links -- links from the area centers to the users.

8.3 Electronic Data Transmission Alternatives.

Data may be transmitted over any of the transmission links by any of a number of transmission alternatives. These alternatives may be classified as either terrestrial or satellite transmission alternatives, as shown in Table 8-1. Each class, together with mail and special

* As stated in Section 4.2.2, the timeliness requirements in the user demand model were selected specifically with a view toward determining network capability and structure for fast (less than nine-day) user-request response time. This rules out the distribution of user data by mail or special courier.

Table 8-1

Electronic Data Transmission Alternatives
by Class of Service

CLASS OF SERVICE	TRANSMISSION ALTERNATIVES
Terrestrial or Land-Line Transmission	Common-Carrier Full Dedicated Common-Carrier Metered User-Owned Terrestrial Microwave
Satellite Transmission	Common-Carrier Full Dedicated Common-Carrier Leased Transponder with User-Owned Earth Terminals Add-On Transponder to Government-Owned Satellite (e.g., SEOS) with User-Owned Earth Terminals User-Owned Satellite and User-Owned Earth Terminals LERS and User-Owned Earth Terminals

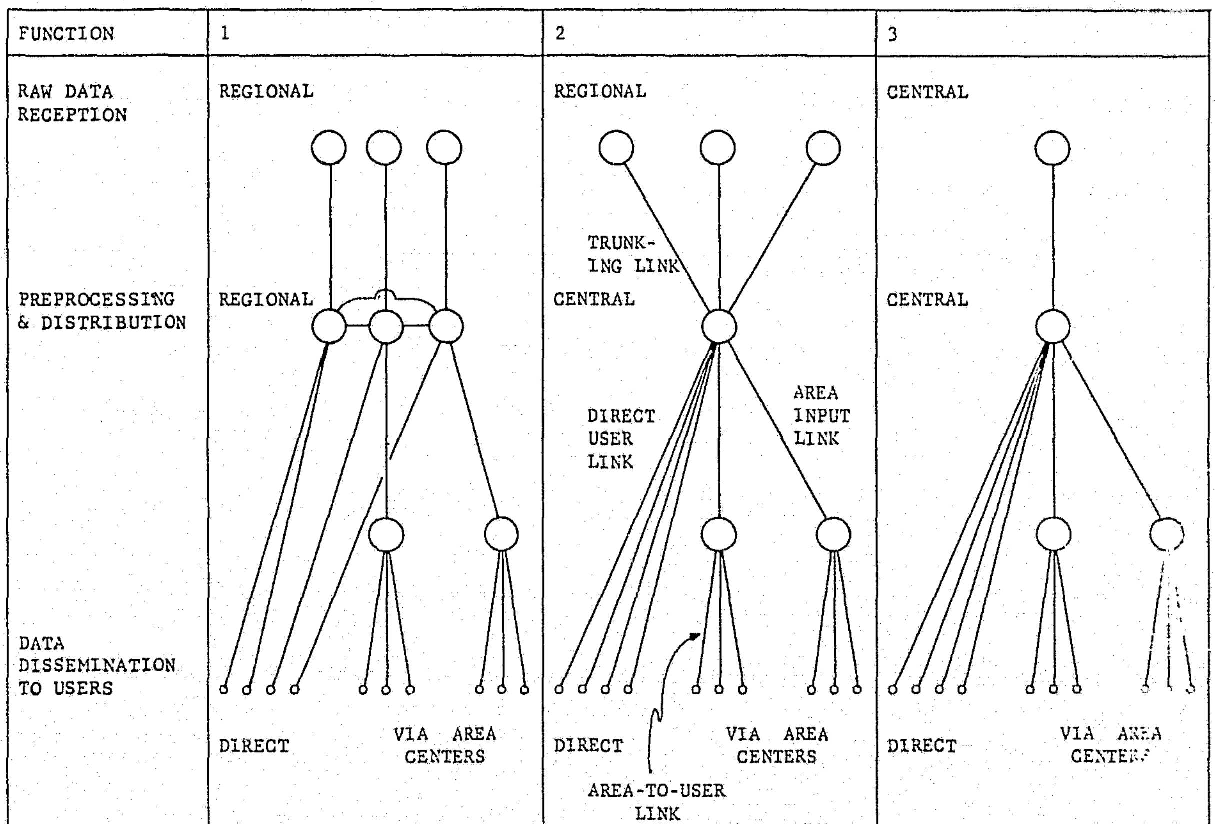


Figure 8-1. Three Generic Classes of Data Dissemination Network Topology

courier service, will, in general, find application for the combinations of user timeliness, user data volume, and transmission link length indicated in Figure 8-2. This figure shows that, for fast data delivery, either land-line or satellite transmission is necessary. In this case, satellite transmission is less costly for transfer of large volumes of data over long distances.

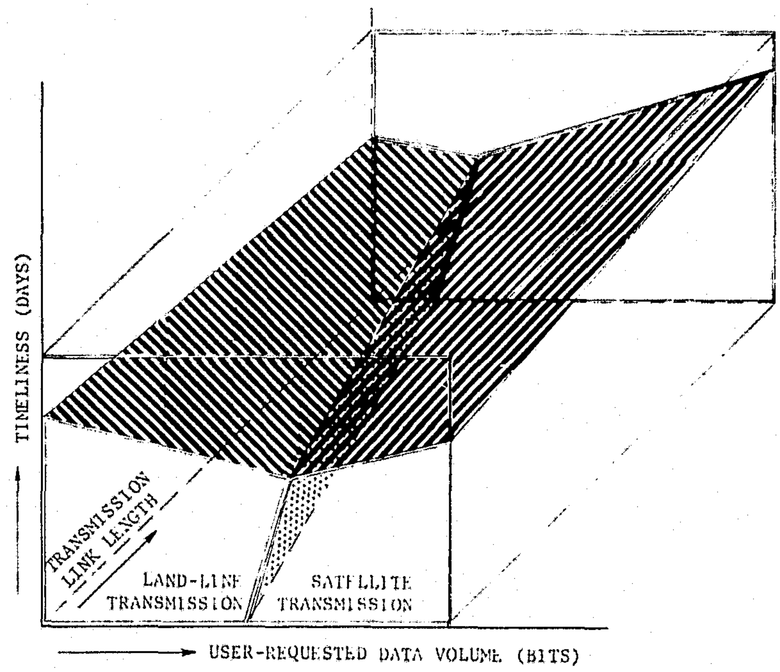


Figure 8-2. General Areas of Least-Cost Service of Three Data Transmission Alternatives

8.4 Cost Comparisons Among Transmission Alternatives

The costs associated with the above transmission alternatives have been detailed in Section 7. To apply these costs to specific transmission links, it suffices to characterize each link in terms of the following four parameters: L, the length of the link; R, the required link data rate; D, the time duration of each transmission; and F, the frequency of the transmission (number of transmissions per year). In the following subsections, the values of these parameters are determined for each of the link types in turn, except for the area-to-user links, and a comparison of transmission alternatives is given. The choice of transmission alternative for area-to-user links is more user-specific than is the case for other links and is critically dependent on factors outside the scope of this tudy (e.g., the cost of user-specific processing and whether it is performed at an area center or at the individual user locations). Given this, and the fact that this choice would not affect the choice of transmission alternative on either area-input or direct-to-user links and would not, therefore, be a factor in selecting from among the three classes of network topology, area-to-user links will not be discussed further.

8.4.1 Trunking Link Transmission Parameters: By definition, trunking links would be established among regional primary terminals, between regional or central primary terminals and a central preprocessor, and between a central preprocessor and a central distributor. Possible sites for these facilities and the resulting possible trunking-link lengths, L, are shown in Figure 8-3. (Not all sites and not every facility at each site would ever be implemented.)

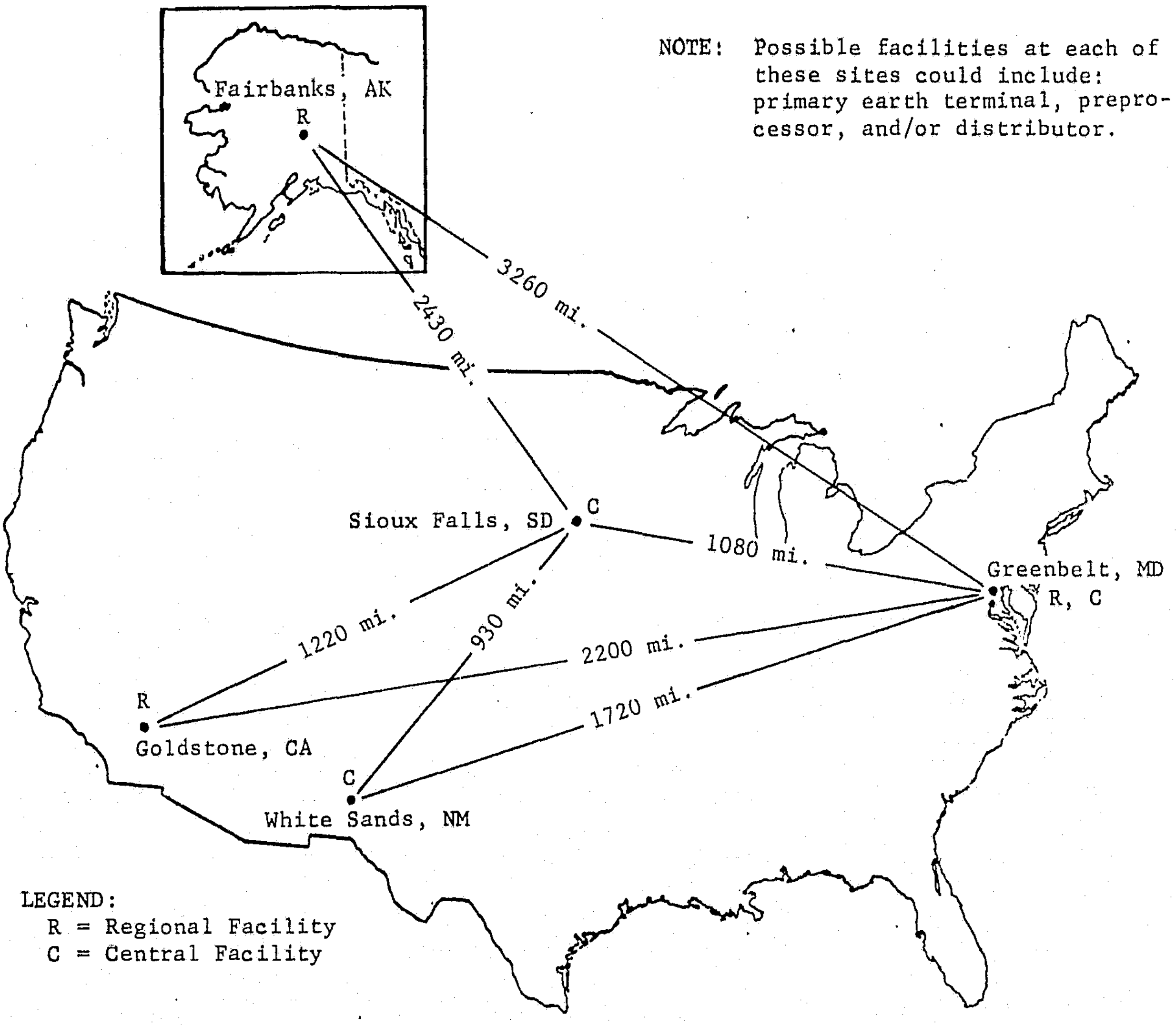


Figure 8-3. Link Lengths, L, of Possible Raw- and Preprocessed-Data Trunking Links

The transmission rates on these links must be at least such that transmission of the raw data that is received and/or preprocessed on any given day can be completed prior to reception of the succeeding day's data. Based on the maximum data volumes in bits, V_{max}, that could be received by each of the above facilities on any one day and on an assumed 16-hour work day (i.e., two shifts) during which continuous transmission would occur, the required transmission rates in bits per second, R, may be approximated by $V_{max}/(16 \times 3600)$. These values of R, the associated values of V_{max}, and the set of swaths that correspond to V_{max} are given in Table 8-2. Because transmission would be continuous, dedicated rather than metered service would be used so D and F need not be determined.

Table 8-2

Required Transmission Rates, R, for Raw and Preprocessed Data Trunking

TRANSMISSION ORIGINATION POINT AND COVERAGE AREA†	TRANSMISSION LINK TERMINATION POINT	SWATH No.'s	V_{max} (Gbits)		R (Mbps)[1]	
			30/7	10/12	30/7	10/12
Goldstone, CA †Western Lower 48 States	Sioux Falls, SD or Greenbelt, MD	30 & 48 and 39	109	1680	1.89	29.1
Fairbanks, AK †Alaska	Sioux Falls, SD or Greenbelt, MD	65 & 83 and 74 & 92	80	1230	1.39	21.4
Greenbelt, MD †Eastern Lower 48 States	Sioux Falls, SD	11 & 29 and 20	91	1410	1.59	24.5
Greenbelt, MD or White Sands, NM †Lower 48 States and Alaska	Sioux Falls, SD or Greenbelt, MD	11, 29, 47, 65 & 83 and 20, 38, 74 & 92	238	3670	4.13	63.7

(1)

$$R = \frac{V_{max} / 10^6}{1 \times 16 \times 3600} = \frac{R_{raw} \times \Sigma L_{SW}/v_g}{1 \times 16 \times 3600 \times 10^6}$$

where V_{max} is the maximum single-day data volume that could be received at each transmission link origination point

R_{raw} is the raw data bit rate from the low-orbit satellites to the primary ET's

ΣL_{SW} is the sum of the lengths of the swaths shown in column 3, and

v_g is the ground trace velocity of the low-orvit satellites

8.4.2 Trunking Link Cost Comparisons: All bit rates for trunking the 30m/7-band data are such that at least a 1.544-Mbps link would be required. For the shortest of the trunking links the costs of the various transmission alternatives at this transmission rate are shown in Table 8-3, along with references to relevant information in Section 7. Since some form of satellite transmission is by far the least expensive alternative, even for this relatively short link, and since, according to Figure 8-2, longer distances and higher bit rates will increasingly favor satellite transmission, the conclusion is inescapable that, where data trunking is required, satellite transmission has significant cost advantages.

Recognizing that the very high transmission rates required for trunking of 10m/12-band data (e.g., as high as 64 Mbps) may restore the cost advantage to the user-owned terrestrial microwave alternative, it is appropriate to investigate this case. The incremental cost for the microwave alternative would be that associated with one more rf channel at each repeater and terminal location (assuming that a single channel would support a transmission speed of 30 Mbps). This would increase the installed cost per repeater from \$76.5K to \$86.5K (see Table 7-27), making the annual cost for the microwave link approximately \$900K.*

* To cover 930 mi. in 30-mi. hops requires (930/30 - 1) = 30 repeaters, plus two terminals. Assuming a terminal cost of \$28K, the initial installed cost of the link is 30×\$86.5K+2×\$28K = \$2.65M. Amortizing this cost over 10 years at 8% interest and adding an annual operations and maintenance cost equal to 20% of the capital cost, the equivalent annual cost of the link is (0.149 + 0.2) × \$2.65M = \$925K.

Table 8-3

The Equivalent Annual Cost ($K) of a Dedicated Transmission Link Between White Sands, NM and Sioux Falls, SD Using Various Alternatives

TRANSMISSION RATE (Mbps)	LEASED TRANSPONDER		ADD-ON TRANSPONDER		COMMON CARRIER		USER - OWNED MICROWAVE (LOS)
	$500K/yr	$1.2M/yr	$800K	$1.6M	LANDLINE	SATELLITE	
1.544	119	165	110 (1)	134 (1)	584 (2)	225 (3)	790
60	595 (4)	1295 (4)	214 (4)	333 (4)	N/A	N/A	925
Relevant Material from Section 7							
Tables	7-22	7-22	7-22	7-22	7-13		7-27
Figures	7-20	7-20			7-4	N/A	7-30
Sections			7.2.3	7.2.3			

(1) Assumes link pays for 1/5 of the cost of the add-on transponder and uses 1/20 of the transponder power. Required ET G/T = 29.4 dB/^{o}K (from Eq. G-1), so cost of terminal is as given in Table 7-21.

(2) Assumes a total of 5 miles of intercity connecting link.

(3) RCA's domestic satellite subsidiary recently contracted with DoD to provide two 1.544-Mbps links and one 64-kbps link between Washington, DC and Camp Roberts, CA at an annual cost of $500K. [1]

(4) Assumes link pays for and uses the entire transponder. Required ET G/T = 31.3 dB/^{o}K. Total equipment cost is as given in Table 7-21 plus $8K for step-track system and $6K more for a larger antenna. These costs of $137K lead to an initial installed cost per terminal of $199K and an annual cost per terminal of $47.5K.

This cost and the corresponding costs for the other alternatives, where available, are also shown in Table 8-3. The add-on transponder (to SEOS, for example) alternative continues as the least-cost alternative. If the add-on transponder alternative is not available, the user-owned microwave facility would be the next-best alternative unless the annual cost of the leased transponder in the UOT/leased transponder alternative were less than approximately $800K.* A precedent for the $800K/year/transponder price was, however, set earlier this year,** and the likelihood is that this price will decrease over the next ten years.

8.4.3 Trunking Link Conclusions: It may be seen from Table 8-3 that a realistic per-link annual cost penalty for land-line rather than satellite trunking of 30m/7-band data using common-carrier facilities would be at least $350K. With a user-owned terminal satellite option, this per-link annual penalty could exceed $450K. The higher data rate of the 10m/12-band data may or may not reduce this penalty but would not, in all probability, eliminate it. Therefore, any trunking of raw or preprocessed data as defined herein should be by satellite transmission.

This conclusion is substantially the same as that reached by National Scientific Laboratories, Inc. during a study of trunking links for ERS data, the final report for which was submitted to NASA GSFC in November of 1974 [3].

* Allows nearly $50K annually for the earth terminals. According to Section 7.2.2.9 and footnote (4) of Table 8-3, this amount is entirely adequate.

** The Public Broadcasting Service will lease three satellite transponders from Western Union at an annual lease price of $2.4M, or $800K per transponder. [2]

8.4.4 Area Input Links Transmission Rates: Agency area centers are intermediate data dissemination centers that serve geographically proximate users who have presumed common or similar data processing needs (e.g., users within an agency of the Federal Government located in the same geographical area). Such centers are being considered in light of possible overall cost savings resulting from: 1) a single shared high data rate area input link, 2) sharing of common processing equipment, 3) reduced length of individual user links from the area centers coupled with 4) lower data volumes (a result of processing) to be sent over the area-to-user links, and 5) the existence of a less congested, closer data bank for the interactive user or for the special courier.

The objective of this subsection is to get a feeling for and to establish a method and rationale for calculating the transmission speeds that would be required on typical area input links. These speeds are a function of the timing of data requests and of the volume of data asked for in each request. Only data that is specifically requested by the user is being considered here, the assumption being that area center archive storage of all area data, if required, could be accomplished by mail.

The basic equation for the average transmission rate, R, required on an area input link is V/T, where V is the volume of data to be transmitted and T is the length of the time period during which transmission must occur. If one is willing to make certain assumptions regarding the timing of data requests and the land area or data volume specified in each request, the values of V and T are contained in information available from the user model; i.e., from area center available data schedules,* user timeliness criteria, and probability of demand. Examples of this information for typical area centers are shown in Table 8-4 and 8-5. These examples are part of the nominal user model derived in Section 5. They show the length of the land area in each swath over which the paricular user has jurisdiction. For example, referring to Table 8-4, the Boise office of the Bureau of Land Management (BLM) is responsible for a 90 n.mi. section of swath 41. The swath- and user-specific land areas are called cells. That is, a "cell" is defined as that portion of a specified swath which an individual user desires. Each user request is for a single cell, in the context of the user model described in Section 5. However, in reality, a user would generally request data from an area encompassing a number of swaths. In the following discussion, the word "request" is used to describe two possible types of "real" user requests in addition to the artificial user request defined in the user model for use in computer simulation. The maps of Figure 8-4 and 8-5 show the locations of the users of Tables 8-4 and 8-5, respectively.

Three possible situations will be introduced and the corresponding values of R determined prior to selecting one situation for use in this study. The situations are realistic. From

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* Available data is data that is available for request by the area center in question. It consists, therefore, of all preprocessed data from land areas within the jurisdiction of that area center. Available data is not sent to the particular area center unless requested.

Table 8-4

Summary by Swath of Cell(1) Lengths in Nautical Miles of the Nominal Demand Model of the Western Region of the Bureau of Land Management

NOTE: Requires 9-day timeliness with 0.333 probability of demand.

USER LOCATION	SATELLITE SWATH NUMBER																	
	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
Billings, MT					100	220	150	220	170	200	190	50						
Boise, ID									90	140	150	120	200	50	25			
Cheyenne, WY				100	140	250	240	170										
Denver, CO		90	100	150	100	230	50											
Phoenix, AZ					90	90	150	200	250									
Portland, OR													100	240	290	340	350	250
Reno, NV										290	320	300	250	210				
Sacramento, CA									25	190	230	150	130	180	190	120	100	
Salt Lake City, UT						25	240	220	230	200								
Santa Fe, NM	25	120	230	310	310													

(1) The portion of swath over which user has jurisdiction.

their associated timing and per-request volume of data requests, they lead to maximum intermediate, and nominal transmission speeds. These situations will be illustrated with the information for the Western Region Area Center of the Bureau of Land Management (BLM) at Denver, Colorado and the Region VII Area Center of the United States Army Corps of Engineers (USACE) at Tulsa, Oklahoma.

In this illustration, it will be assumed that 1- and 2-day timeliness data will be received, trunked to the central preprocessor, and preprocessed in one-half day (8 hours), and that the 5- and 9-day timelinesss data will exit the preprocessor one full day (16 hours) after reception from the LERS sensors.

8.4.4.1 <u>All Area Land Per Request</u>: The first situation involves a single request for the entire land area under area center jurisdiction. This request would be submitted to the distribution center with probability p during every 9-day satellite coverage cycle.* Data for all cells of the entire area would then be transmitted to the area center as soon after the request as it is received from the LERS satellites and preprocessed. This situation may occur, for example, if all area users are subject to a coordination directive from the area center that requires near-simultaneous coverage of all area land.

* A coverage cycle is the period of time, in days, between successive passes of a satellite (not necessarily the same satellite) over a given cell. With two LERS satellites, the coverage cycle is 9 days.

Table 8-5

Summary by Swath of Cell(1) Lengths in Nautical Miles
Model of the United States Army Corps of

NOTE: Requires 5-day timeliness with 0.33 probability of demand.

USER LOCATION	SATELLITE SW																					
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	3
Region I																						
Boston, MA	70	230	330																			
Providence, RI			70	220																		
Region II																						
New York, NY			25	90	290	40																
Philadelphia, PA					160																	
Baltimore, MD					60	280	270															
Norfolk, VA					80	90	30															
Region III																						
Wilmington, NC					120	180	140															
Charleston, SC						180	180	190	50													
Jacksonville, FL						180	200	100	110													
Savanah, GA								200	170	40												
Mobile, AL										310	260	250	260									
Region IV																						
Pittsburgh, PA								250	100													
Huntington, WV								40	180	190	50											
Nashville, TN								90	120	150	170	140	160	25								
Louisville, KY										50	180	270	270	230								
Region V																						
New Orleans, LA													60	150	110	100	70	25				
Memphis, TN														140	200							
Vicksburg, MS														200	160	80						
St. Louis, MO														180	160	170	50					
Region VI																						
Buffalo, NY						110	120	110	110	270	40											
Detroit, MI											320	330	320	310								
Chicago, IL														140	400	150						
St. Paul, MN															130	210	340	270	300	300	280	2
Rock Island, IL																250	180	160	120	25		
Region VII																						
Little Rock AR																200	160					
Galveston, TX																60	130	260				
Fort Worth, TX																70	100	170	430	340	260	1
Tulsa, OK																	60	270	270	310	300	24
Albuquerque, NM																					25	1
Region VIII																						
Kansas City, MO																25	160	220	210	110	150	12
Omaha, NE																				190	190	3
Region IX																						
Walla Walla, WA																						
Seattle, WA																						
Portland, OR																						
Region X																						
Los Angeles, CA																						
Sacramento, CA																						
San Francisco, CA																						

(1) That portion of swath over which user has jurisdiction.

FOLDOUT FRAME /

Table 8-5

Lengths in Nautical Miles of the Nominal Demand
nited States Army Corps of Engineers

S A T E L L I T E   S W A T H   N U M B E R

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
100 80 170	70 50	25																								
150 210 250	340 180	270 160	300 120	300 25	280	210	150	80	80	50	25															
200 60 70	160 130 100 60	260 170 270	430 270	340 310	260 300 25	170 240 160	160 180 240	80 440	470	500	150															
25	160	220	210	110 190	150 190	120 310	140 350	120 420	520	560	510	470	410	390												
															120	150	190 60	280 200	350 130	350 130	210 120 170	120 180 140	160 320	140 310	150 25	80
											540	610	650	740	320 310	380 260	370 220	310 210	50 440	25 400 25	90	210	210			

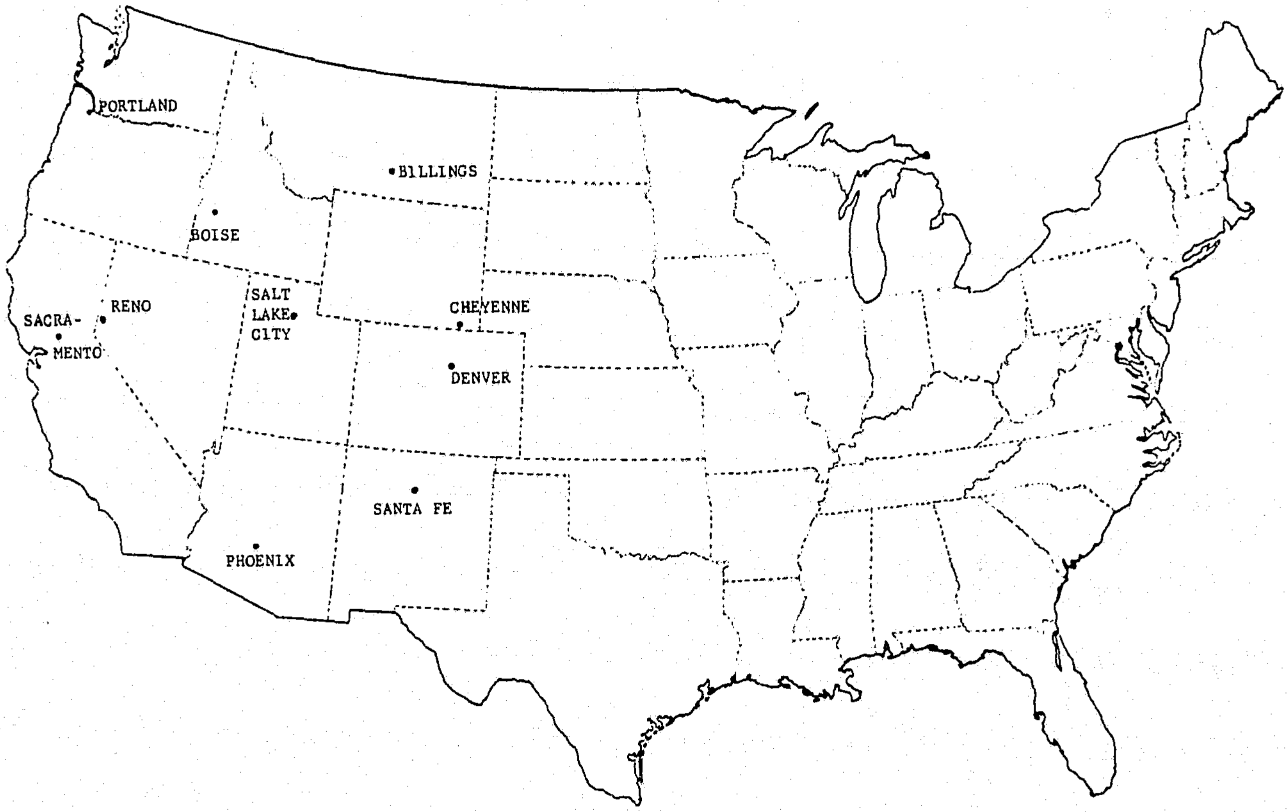


Figure 8-4. User Locations in the Western Region of the Bureau of Land Management

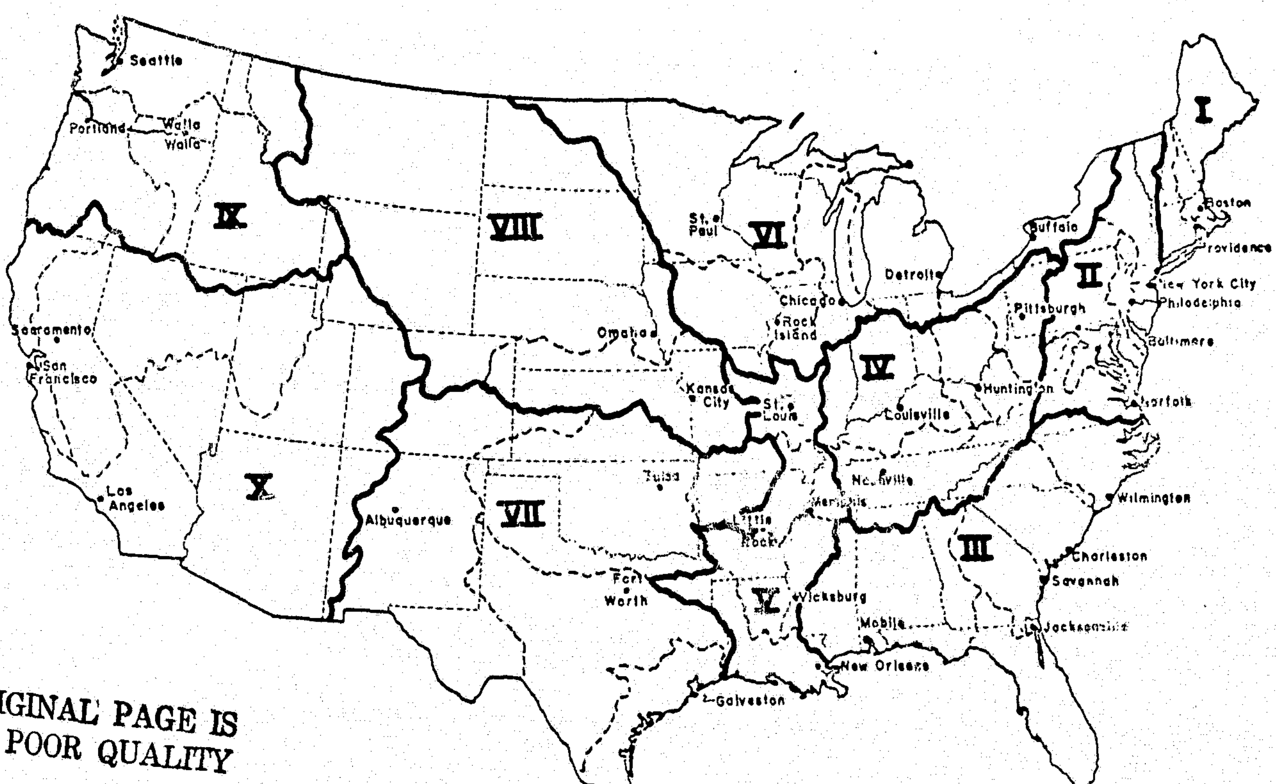


Figure 8-5. User Locations in the Ten Regions of the United States Army Corps of Engineers

Using the nominal demand model with 30m/7-band data for the BLM area center, a request for data for all of the cells of Table 8-4 would be sent to the distribution center on an average of every 27 days.* In this case, the data volume, V, would be 268 gigabits and the period for data transmission, T, would be 17 days (9 days during which data is received plus 9 days allowed by user timeliness minus 1 day preprocessing delay). Without considering the effect of cloud cover, this would require R to be 274 kbps. The corresponding value of R for the USACE Region VII Area Center is 208 kbps.

8.4.4.2 All Single-User Land Per Request: In the second situation, the individual users associated with any given area center would generate independent requests for data. Each request would, however, encompass all of the data for the land under the corresponding user's jurisdiction and would, as before, be submitted to the distribution center with probability p during every 9-day satellite coverage cycle. This situation could occur, for example, if each user desired to achieve near simultaneous coverage of all his land area.

Assuming further that an area center directive requires that each user request be scheduled within the (9/p)-day average request cycle to avoid simultaneity and reduce R, the nominal demand user request schedule over a 27-day period for the BLM Area Center might then appear as shown in Table 8-6. In this table, the heavy black lines associated with the cells of a given user indicate the time period, T, during which transmission would occur. The corresponding R is 187 kbps. For the USACE Region VII users, this situation produces an R of 133 kbps. The associated nominal demand user request schedule is given in Table 8-7.

8.4.4.3 Single Cell Per Request: In the third situation, not only would users submit independent requests for data from their own land, but also requests for individual cells within a given user's jurisdiction would be submitted independently. Data for a cell would be requested from the distribution center with probability p every time a satellite passes over that cell.

To illustrate, data requests for only one-third (p = 0.33) of the cells would be submitted from the BLM Area Center to the distribution center during a typical 9-day period. Therefore, V would be 89.3 gigabits and T would be 9 days, giving an R of 172 kbps. If one supposes that cloud cover** and various other causes of schedule perturbation could intermittently increase the normal 9-day demand for cells from one-third of them, or 20.3, to 31.4 (the 3σ point obtained using a binomial probability law with n = 61 and p = 0.33), R would have to be 266 kbps.

* With a probability of demand of 0.33, meaning that, on the average the data from two out of every three satellite passes of a given cell will not be requested, the average request cycle is 27 days (9/0.33).

** Data that is obtained over land obscured by clouds is less desirable than cloud-free data. Clouds can, in fact, render the data useless. The effect of cloud cover, therefore, will be a bunching, or concentrating, of the data requests to coincide with cloud-free passes.

Table 8-6

A Possible BLM Western Region Area Center Sched
Corresponding to All Single-User Land per Re

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
SWATH	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	33	34
SATELLITE ONE																				
Billings					100	220	150	220	170	200	190	50								R_{av}
Boise		R_{avg} = 33.8 kbps																		
Cheyenne																				
Denver																				
Phoenix																				
Portland																				
Reno																				
Sacramento									25	190	230	150	130	180	190	120	100			
Salt Lake City																				
Santa Fe																			25	150
SWATH	42	43	44	45	46	47	48	49	50	33	34	35	36	37	38	39	40	41	42	43
SATELLITE TWO																				
Billings																				
Boise																		90	140	150
Cheyenne						R_{avg} = 39.3 kbps														
Denver											90	100	150	100	230	50				
Phoenix														90	90	150	200	250		
Portland				100	240	290	340	350	250										R_{avg} =	
Reno	290	320	300	250	210							R_{avg} = 59.8 kbps								
Sacramento																				
Salt Lake City	200									R_{avg} = 33.3 kbps										
Santa Fe					R_{avg} = 37.3 kbps															

The Overall Data Rate Required to Accommodate Each Day's Scheduled
(Σ of each day's R_{avg}) in kbps:

144	170	170	170	181	182	182	182	182	187	187	156	156	156	184	184	184	185	170	166

$\therefore$ Required Data Rate, R_a = 191 kbps

FOLDOUT FRAME 1

able 8-6

n Region Area Center Schedule
Single-User Land per Request

14	15	16	17	18	19	20	21	22	23	24	25	26	27	
46	47	48	49	50	33	34	35	36	37	38	39	40	41	
						R_{avg} = 40.5 kbps								
								100	140	250	240	170		
80	190	120	100								R_{avg} = 38.2 kbps			
										25	240	220	230	
					25	150	230	310	310					
37	38	39	40	41	42	43	44	45	46	47	48	49	50	
				90	140	150	120	200	50	25				
00	230	50							R_{avg} = 28.5 kbps					
90	90	150	200	250										R_{avg} = 28.4 kbps
					R_{avg} = 48.9 kbps									
.8 kbps														

SATELLITE ONE NOW BECOMES SATELLITE TWO

SATELLITE TWO NOW BECOMES SATELLITE ONE

date Each Day's Scheduled Transmissions
day's R_{avg}) in kbps:

56 184 184 184 185 170 166 166 166 177 177 172 172 144

ta Rate, R_a = 191 kbps

FOLDOUT FRAME 2

Table 8-7

A Possible USACE Region VII Area Center Schedule Corresponding to
All Single-User Land per Request

DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
SWATH	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	26	27	28	29	30	31	32	33	34
SATELLITE ONE																											
Little Rock																			200	160					R_{avg}=26.2kbps		
Galveston																			60	130	260				R_{avg}=28.0kbps		
Ft. Worth	70	100	170	430	340	260	170	160					R_{avg}=61.7kbps														
Tulsa		60	270	270	310	300	240	180	80					R_{avg}=62.1kbps													
Albequerque																											
SWATH	35	36	37	38	39	40	41	42	43	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43
SATELLITE TWO																											
Little Rock																											
Galveston																											
Ft. Worth																											
Tulsa																											
Albequerque															25	160	240	440	470	500	150				R_{avg}=78.6kbps		

The Overall Data Rate Required to Support Each Day's
Scheduled Transmissions, in kbps (Σ of each day's R_{avg}'s):

0 62 124 124 124 124 124 124 124 124 124 124 124 62 0 79 79 79 79 133 133 133 133 133 133 107 0

∴ Required Data Rate, R_a = 151 Kbps

Applied to the nominal demand model for the USACE Region VII Area Center, this set of assumptions produces a data rate of 100 kbps, with a 3σ rate of 181 kbps. All three sets of assumptions and the corresponding values of R are tabulated in Table 8-8.

Table 8-8

Required Data Rates from a Central Preprocessor to Area Centers for Three Different Situations

(kbps)

SITUATION	AREA CENTER	
	BLM WESTERN REGION AREA CENTER AT DENVER, COLORADO (Nominal Demand)	USACE REGION VII AREA CENTER AT TULSA, OKLAHOMA (Nominal Demand)
1) Near-simultaneous coverage of all area land	274	208
2) Single-user simultaneous coverage, only	187	133
3) Single-cell simultaneous coverage, only (3σ rate)	172 (266)	100 (181)

8.4.4.4 Influence of the Probability of Demand: When the probability of demand, p, changes, the effect on the above data rates is not uniform. Under the first situation, R does not change at all; only the frequency of data transfer to the area center would change. Under the second situation, R decreaces as p decreases, although not proportionally, but does not decrease below the value required by the most demanding single user. In the BLM Western Region, this user is Portland with an R of 49 kbps (see Table 8-6; if the allowed full 13-day transmission time were scheduled for Reno -- which could be done if the frequency of transmission were reduced -- the associated R would be 45.9 kbps which is less than 49 kbps). For USACE Region VII, Albuquerque is the most demanding single user with R of 79 kbps (see Table 8-7).

Under the third situation, R is proportional to p but cannot be less than the rate required to complete transmission, within the user timeliness constraint, of the data for the longest cell. That is,

$$R \propto \max\left[\frac{pnL_{c,avg}}{C}, \frac{L_{c,max}}{U-D}\right]$$

where $L_{c,avg}$ is the average cell length within the area,

$L_{c,max}$ is the length of the longest cell within the area,

C is the coverage cycle for any particular user cell,

n is the number of cells in the area,

p is the probability that the data available from any given satellite coverage cycle will be requested,

U is the user timeliness requirement, in days, and

D is the assumed delay, in days, for preprocessing.

For the two areas used in the illustration, the value of p is large enough that both data rates under the third situation are still proportional to p. In order that the data rates to the BLM Western Region and the USACE Region VII be governed by the user timeliness constraint rather than by the probability of demand, p would need to be less than 0.037 and 0.18, respectively. These values of p correspond, in the present case, to average intervals of 244 days and 50 days, respectively, between successive requests for data from the same piece of land.

8.4.4.5 Choice of Assumptions for R: The foregoing discussion of transmission rates underscores the uncertainty that accompanies estimates of rates that are likely to be required in an operational system. Furthermore, the uncertainty is compounded by the fact that the choice of the value of p, the probability of demand, is, itself, somewhat arbitrary. In the face of this uncertainty, a desire to avoid favoring satellite over land-line transmission, and a feeling that one effect of cloud cover on data availability will be the creation of a situation that encourages a single-cell-per-request demand schedule, the third situation will be assumed in computing transmission rates for this study. This assumption leads to the required area input link transmission rates shown in Table 8-9 for the ten USACE regions (30m/7-band data using the nominal demand model shown in Table 8-5).

8.4.4.6 Computer Simulation of Area Input Links: To validate the approach taken above in calculating the average transmission rates required on area input links, the single-cell-per-request model was simulated on a computer for the BLM Western Region and for Regions IV and VII of the USACE. The simulation program is similar to that of the main simulation program (see Section 10) but reduced in scope. The relative timing of the reception of satellite data is preserved, assuming no cloud cover; i.e., that all the data from all the passes of both satellites are received at the time the satellites pass over. The demand for this data is determined by applying the probability of demand on a cell-by-cell basis. Those cells for which a demand exists are passed to the preprocessor queue, and thence, in turn, to the preprocessor, to the transmitter queue, and finally, to the transmitter. After transmission is completed, the system time is recorded for user timeliness statistics.

The preprocessor speed was assumed to be that appropriate for the 1980 to 1985 time frame. Even though faster preprocessors will become available during the 1985 to 1995 period, it was judged that the effect of having only a single area center's or end user's data load on the preprocessor would more than offset the effect of a slower preprocessor speed. The resulting transmission rates are, therefore, probably too low. Only the LERS-to-primary earth terminal data rate associated with 30m/7-band data was simulated.

Table 8-9

Transmission Rates on the Area Input Links to the Ten USACE Regions

- Single-Cell-per-Request Situation -
- 30m/7 Band, Nominal User Demand -

AREA CENTER	R_a (kbps)	DISTANCE FROM SIOUX FALLS (mi.)
Region 1 - Boston, MA or Providence, RI	36	1287
Region 2 - Baltimore, MD	32	1080
Region 3 - Savannah, GA or Mobile, AL	50	1000
Region 4 - Louisville, KY or Huntington, WV	43	678
Region 5 - Memphis, TE	30	677
Region 6 - St. Paul, MN or Rock Island, IL	95	201
Region 7 - Tulsa, OK or Albuquerque, NM	100	507
Region 8 - Omaha, NB	90	175
Region 9 - Walla Walls, WA	66	1075
Region 10 - Sacramento, CA or Los Angeles, CA	103	1329

The results of the simulation, recorded in Table 8-10, do indeed confirm the accuracy of the method used to calculate the area input link transmission speeds. As expected, the delay due to preprocessing was only a few minutes and is not shown separately.

8.4.5 Area Input Link Lengths: The links to the area centers of the ten USACE Regions can be considered as representative of area input links. Airline distances between possible central or regional distributor locations and the nearest end user in each of these ten regions are shown in Figures 8-6 and 8-7. With a central distributor at Sioux Falls, SD, the average link length to area centers is about 800 mi. With regional distributors located at Goldstone (los Angeles) and Greenbelt (Baltimore), the average link length is a little over 600 mi.

8.4.6 Frequency of Use and Duration of Use of Area Input Links: Implicit in the calculation of the area input link data rates just completed, and verified by the near unity average utilities shown in Table 8-10, is the requirement for dedicated links between the distributor and the area centers. In other words, use of the link is practically continuous and, consequently, the parameters F and D have no meaning. (They are relevant only when metered service must be considered.)

Table 8-10

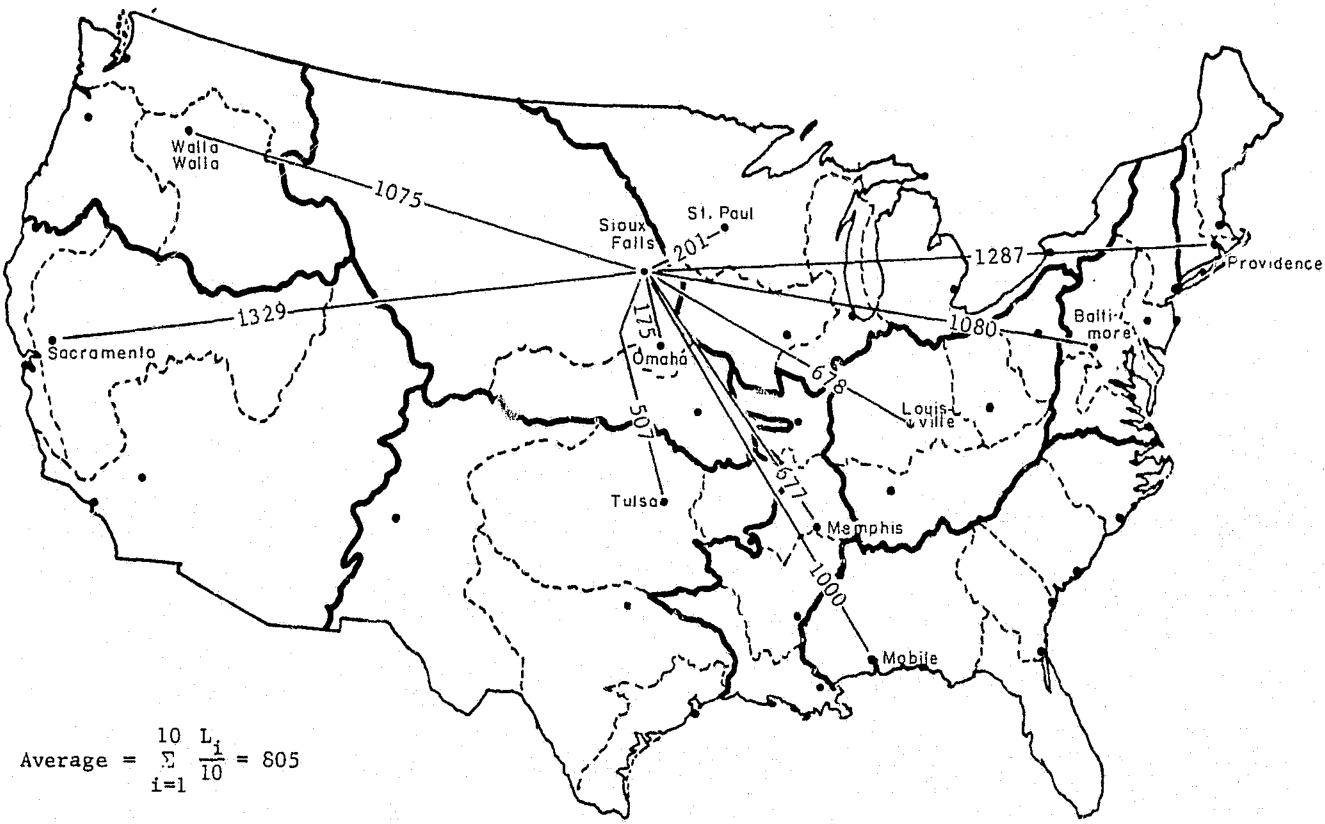
Results of Computer Simulation of Area Input Links

Assumed 1982 Preprocessor Speed

AREA CENTER LOCATION	TRANSMISSION QUEUE			TRANSMISSION FACILITY			ARRIVAL STATISTICS		
	AVERAGE TIME/ TRANS. (hrs)	MAXIMUM CONTENTS	PRESENT CONTENTS	SPEED (kbps)	AVERAGE TIME/ TRANS. (hrs)	AVERAGE UTILITY	AVERAGE REL. ARR. TIME (1) (hrs)	MAXIMUM LATE (hrs)	PERCENT LATE IN ARRIVING (2)
BLM - DENVER, CO Nominal Demand 30/7 Data Rate	345.58	75	73	70	16.3	0.9999	145.06	~ 450	72.9
	50.51	16	13	172	7.0	0.9473	-158.35	-	0.0
USACE IV - LOUISVILLE, KY Nominal Demand 30/7 Data Rate	13.97	3	0	70	16.10	0.6648	- 83.05	-	0.0
	42.79	4	3	47	24.34	0.9128	- 50.90	35	10.4
USACE VII - TULSA, OK Nominal Demand 30/7 Data Rate	233.5	22	20	70	22.8	0.9999	167	345	94.1
	57.35	6	5	100	15.80	0.9972	- 40.51	5	12.3
	15.02	4	0	140	11.3	0.7767	- 88.76		0.0

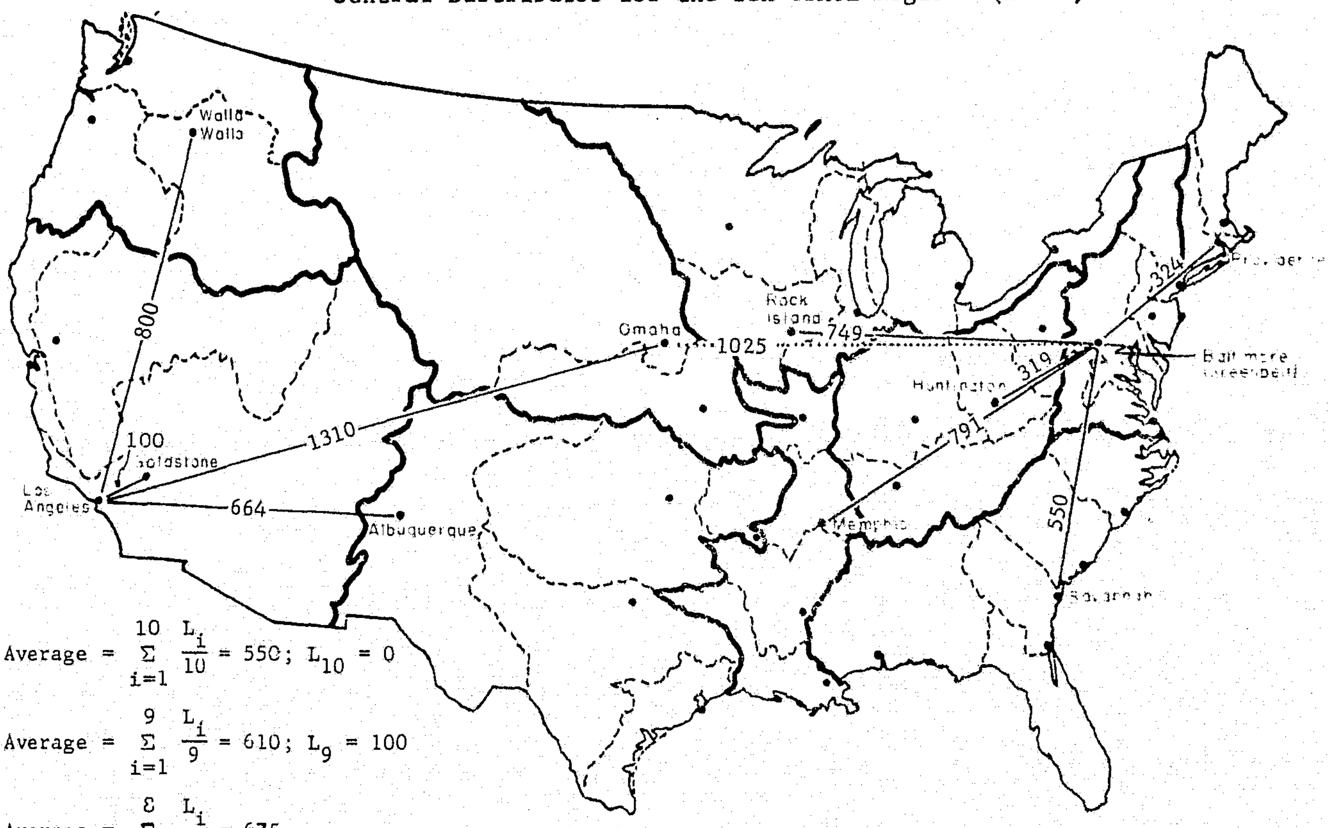
(1) Average relative arrival time is referred to the user timeliness requirements. If the data arrives late, the value is positive. If the data arrives early, the value is negative.

(2) Percent late in arriving does not take into account those cells still waiting in queues.



$$\text{Average} = \sum_{i=1}^{10} \frac{L_i}{10} = 805$$

Figure 8-6. Transmission Link Lengths of Typical Area Input Links from a Central Distributor for the Ten USACE Regions (Areas)



$$\text{Average} = \sum_{i=1}^{10} \frac{L_i}{10} = 550;\ L_{10} = 0$$

$$\text{Average} = \sum_{i=1}^{9} \frac{L_i}{9} = 610;\ L_9 = 100$$

$$\text{Average} = \sum_{i=1}^{8} \frac{L_i}{8} = 675$$

Figure 8-7. Transmission Link Lengths of Typical Area Input Links from Regional Distributors for the Ten USACE Regions (Areas)

8.4.7 Cost Comparison for Area Input Links: The transmission speeds required on typical links are such that, for common-carrier service, at least a 56-kbps link would have to be considered. (Note: Even where a 30- to 36-kbps link would suffice, Figure 7-6 indicates that the cost of a 56-kbps link is less than that of a 36-kbps link if the latter is composed of four standard-cost 9.6-kbps links; and this would not include the data splitter required to form four separate 9.6-kbps bit streams from a single 36-kbps stream and then to recover the original stream at the receiving end.) At this and lower speeds, there is not much difference in cost between similar service offerings of the satellite common carriers and the land-line common carriers. In what follows, therefore, the costs for these two alternatives will be assumed to be the same.

Since the cost of a user-owned terrestrial microwave facility is clearly not competitive with that of common-carrier service at these speeds (compare Figures 7-6 and 7-30), the choice of transmission alternatives for area input links and direct-to-user, and for area-to-user links as well, is between a UOT satellite system and common-carrier service.

It is convenient at this point to prepare a general comparison of common-carrier land-line transmission costs with UOT satellite transmission costs. For the moment, let us restrict this cost comparison to three transmission speeds that are commonly offered by the common carriers. For each transmission speed, a maximum and a minimum expected cost of service with the UOT satellite system will be determined from Figures 7-19 and 7-23 through 7-27. Then, from the dedicated land-line service cost curves of Figure 7-6, crossover distances corresponding to the two expected satellite system costs will be determined. For minimum-cost transmission, link lengths shorter than the shorter crossover distance should be served by land line. Link distance longer than the longer crossover distance should be served by satellite.

Suppose first that 56-kbps transmission is required. From the aforementioned figures, the annual cost per user for UOT satellite transmission is shown to be between $15K and $28K (assuming that 1 MHz split amoung 20 users will support data rates of 56 kbps per user). From Figure 7-6, the annual cost of a dedicated leased 56-kbps link exceeds $15K for distances greater than approximately 160 miles. It exceeds $28K for distances greater than approximately 440 miles. If 9.6 kbps is required, the annual UOT satellite system costs are between $10K and $20K per user (assuming that 1 MHz split amoung 100 users will support data rates of 9.6 kbps per user). The corresponding annual cost for dedicated land-line service exceeds these figures for distances greater than 560 miles and 1560 miles, respectively. When a 2.4-kbps transmission speed is considered, there is more uncertainty associated with the satellite charges in the UOT satellite system than when the higher data rates are considered. Nevertheless, the cost of the service should still be bracketed by the options specified in Section 7. Thus, assuming that 1.2 MHz split among 500 users will support data rates of 2.4 kbps, the UOT satellite system cost will be between $8K and $17K per year, which corresponds to distances of 1240 miles and 3100 miles, respectively, of equivalent land-line service.

Using these three point-pairs to construct smooth curves in data-rate/link-length space, Figure 8-8 results.

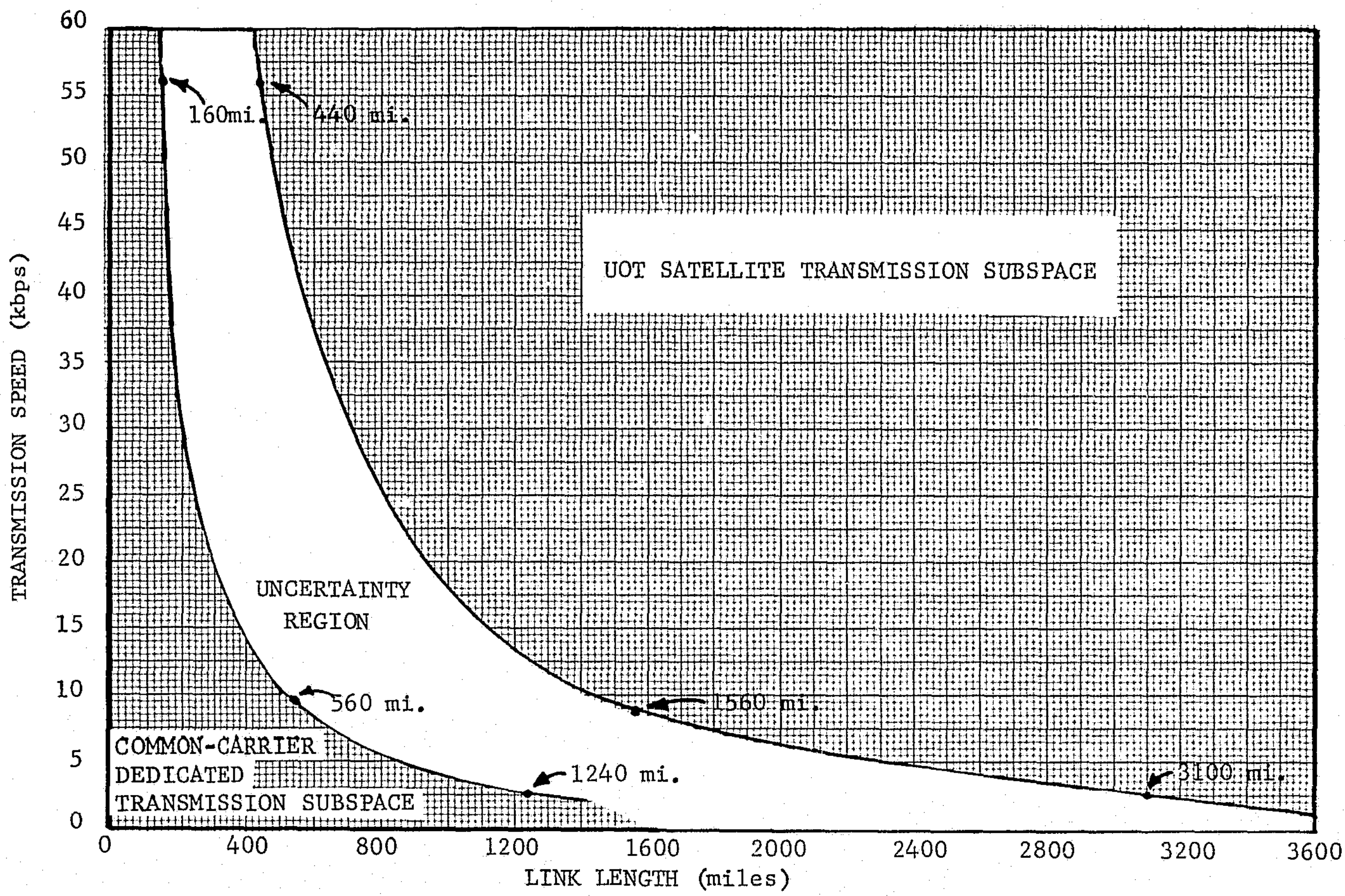


Figure 8-8. Combinations of Transmission Speed and Link Length for Least-Cost Service -- Comparing UOT Satellite Transmission with Common-Carrier Dedicated Transmission

8.4.8 <u>Conclusion - Area Input Links</u>: Entering Figure 8-8 with an average area input link length of 700 miles (see Figure 8-6 and 8-7) and a required transmission speed of 56 kbps (see Table 8-9), the conclusion is that, for the present model of user demand, UOT satellite transmission rather than common-carrier transmission should be used on most area input links for least-cost service. Common-carrier transmission might be used on the shorter links if the required transmission speeds are not greater than 56 kbps.

One should also bear in mind that, for area centers not located where a 56-kbps service is available or planned (see Figures 7-11 and 7-12), dedicated or metered common-carrier service will not even be possible.

8.4.9 Direct-to-User Link Transmission Rates: Using the earlier decision that user demand will be modeled on a "single-cell-per-request" basis, the required transmission rates to individual users, not accounting for the effects of cloud cover, were calculated for each user in the BLM Western Region and in USACE Regions IV and VII. They are shown in Table 8-11. The method used was to first determine the transmission rate, $R_{c,max}$, needed for the largest single cell of the user in question. Next calculated was the transmission rate, R_{max}, that would be necessary if data for all of the users' cells were demanded during any single 9-day coverage cycle -- a maximum composite demand situation. The required transmission rate, R, was then estimated to be the sum of $R_{c,max}$ and one-third of the difference between $R_{c,max}$ and R_{max}.

As with the method used in calculating area input link transmission rates, this method was checked by computer simulations. The program was identical to that described in Section 8.4.4.6. In this instance, direct-to-user links were simulated using the actual estimated transmission rate (Table 8-11) for users in USACE Region VII only. The results of the simulations are given in Table 8-12. They tend, in general, to validate the method for calculating direct-to-user link transmission rates.

Two observations suggest themselves as one compares the results of these computer simulations with those of the area input link simulations. First, the average utility of the transmission facility cannot be used as a guage of the adequacy of the facility. This is seen in the fact that, for area input links, the average utilities were over 0.90 while, for the direct-to-user links, the average utilities were as low as 0.22.* Yet, in both cases, the links provided close to 100% on-time service.

A merely equivalent performance (compared to area input link performance) from relatively idle direct-to-user links, although a seeming contradiction, occurs because their transmission speeds must be governed by the user timeliness criterion rather than by the probability of demand. Or, using the equation of Section 8.4.4.4, R must be proportional to $L_{c,max}/(U-D)$ rather than to $npL_{c,avg}/9$. The actual values of R used in the direct-to-user link simulations were only slightly higher than required to meet the user timeliness criterion for data on the largest single cell. Therefore, in these cases, regardless of how infrequently one chooses to make the request for data -- i.e., regardless of how small one makes the probability of demand, and, consequently, of how infrequently the link is used -- the transmission speed may not be decreased significantly and still provide on-time performance for all user data. (Where the probability (frequency) of demand is very low, use of metered rather than dedicated common-carrier service should be considered.)

* This figure is estimated as follows. The average utility of the direct-to-user link for Galveston, TX, given in Table 8-12 is 0.21. Since there were no unsatisfied users for the associated transmission rate of 29.8 kbps, a reduction in transmission rate is possible. A lower bound on the rate is 28.3 kbps, which is $R_{c,max}$, the rate needed for the largest single cell in Galveston's jurisdiction. The average utility occasioned by an R of 28.3 kbps would be approximately equal to the average utility occasioned by the 29.8-kbps rate times the ratio of 29.8 to 28.3. Or 0.21 x 1.05 = 0.22.

Table 8-11

Required Transmission Rates on Direct-to-User Links in BLM Western Region and USACE Regions IV and VII

USER LOCATION	REQUIRED TRANSMISSION RATES (kbps)
BLM Western Region	
Billings	20.6
Boise	15.3
Cheyenne	20.1
Denver	16.4
Pheonix	18.6
Portland	30.3
Reno	28.2
Sacramento	32.2
Salt Lake City	19.4
Santa Fe	23.7
	Σ = 224.8
USACE Region IV	
Pittsburgh	28.5
Huntington	23.5
Nashville	25.0
Louisville	37.9
	Σ = 114.9
USACE Region VII	
Little Rock	25.1
Galveston	29.8
Fort Worth	53.8
Tulsa	45.3
Albuquerque	65.2
	Σ = 219.2

Table 8-12

Results of Computer Simulation of Direct-to-User Links

AREA & USER LOCATION	TRANSMISSION QUEUE			TRANSMISSION FACILITY			ARRIVAL STATISTICS		
	AVERAGE TIME/ TRANS. (hrs)	MAXIMUM CONTENTS	PRESENT CONTENTS	SPEED (kbps)	AVERAGE TIME/ TRANS. (hrs)	AVERAGE UTILITY CORRECTED	AVERAGE REL. ARR. TIME (1) (hrs)	MAXIMUM LATE (hrs)	PERCENT LATE IN ARRIVING (2)
USACE Region VII									
Little Rock	0	1	0	25.1	50.3	0.25	- 49.7		0
Galveston	0	1	0	29.8	33.2	0.21	- 77.0		0
Fort Worth	10.47	2	0	53.8	26.8	0.50	- 70.1	~15	7.1
Tulsa	24.83	2	0	45.3	31.9	0.52	- 49.6	~35	7.7
Albuquerque	21.28	2	0	65.2	32.0	0.72	- 53.5	~75	11.8

(1) Average relative arrival time is referred to the user timeliness requirements. If the data arrives late, the value is positive. If the data arrives early, the value is negative.

(2) Percent late in arriving does not take into account those cells still waiting in queues.

Second, it is apparent that the sum of the transmission speeds required on the direct-to-user links is much larger (by factors of 1.3, 2.7, and 2.2 for the BLM Western Region and the USACE Regions IV and VII, respectively) than the transmission speed required on the associated area input links. This observation would hold true in general, suggesting that area centers may be cost effective if a strictly land-line distribution network were implemented, even if no processing (i.e., classification) is done at the center.

8.4.10 Link Lengths: User locations will be clustered around their respective area centers. Some will be closer to, and some further from the preprocessor/distributor location than is the area center. One may expect, therefore, that the average direct-to-user link length will be approximately equal to the average area input link length; i.e., 600 to 800 miles.

8.4.11 Frequency of Use and Duration of Use: The average utilities of the links in USACE Region VII vary from 0.21 to 0.72. (See Tables 8-10 and 8-12.) Quite probably, therefore, the minimum average utility on a direct-to-user link would be approximately 0.20. (Little Rock and Galveston are among the lowest volume users in any of the ten USACE regions, having jurisdiction over only 2 and 3 cells, respectively.) This suggests that metered, rather than dedicated service might be better suited for these links since, on an annual basis, they would only be used for a total of 75 days of transmission rather than a full 365 days. Re-plotting, in Figure 8-9, the data given in Figures 7-8 and 7-9 to show the crossover usage, in days, between metered and dedicated service, it is evident, however, that dedicated service is still the least-cost alternative. F and D do not, as a consequence, need to be determined.

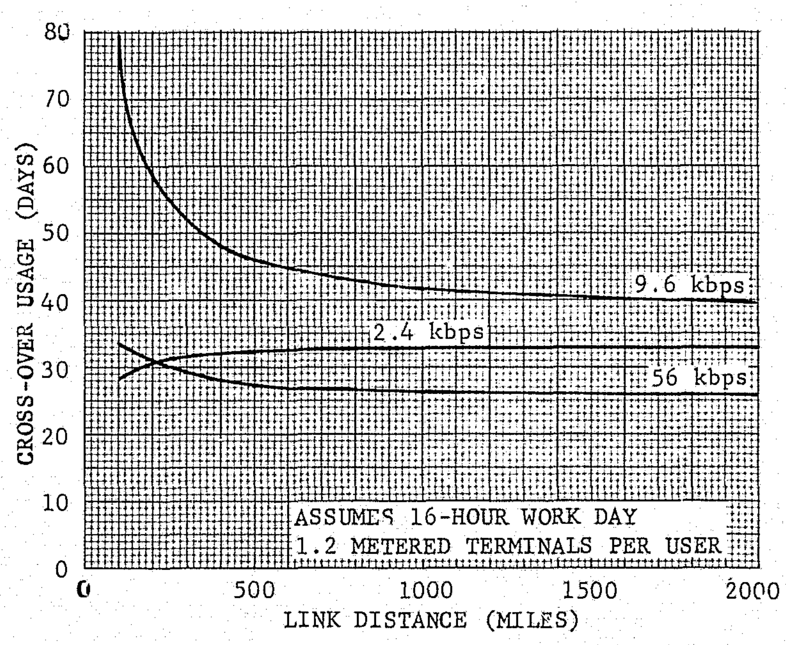


Figure 8-9. Cross-Over Usage between Metered and Dedicated Common-Carrier Service at 2.4, 9.6, and 56 kbps

8.4.12 Cost Comparison: As dedicated lines have been determined to be less costly than metered lines on direct-to-user links -- given the present user demand model -- Figure 8-8 can be used for this comparison. Required bit rates will range from about 9.6 kbps to 56 kbps and higher. The average link length will be about 700 miles. With these figures in mind, Figure 8-8 indicates that the choice between common-carrier and UOT satellite transmission is somewhat uncertain for the shorter, lower-speed links. It also shows, however, that notwithstanding this small uncertainty, a UOT satellite transmission system will be the least-cost alternative on the majority of the direct-to-user links -- more especially where required transmission speeds are more than two and a half to three times the standard 9.6-kbps offering. (Remember that the annual cost of a 56-kbps link is only between three and four times that of an equal-length 9.6-kbps link.)

8.4.13 Conclusion - Direct-to-User Links: In the general case, least-cost transmission on direct-to-user links will require the use of a UOT satellite system. This conclusion could be stated even more strongly where an add-on transponder could be used.

8.5 Summary

The discussion of Section 8 has shown that data dissemination by electronic transmission on a scale commensurate with the user demand model of Section 5 is accomplished at least cost with some variation of a user-owned-earth-terminal satellite system.

The discussion has been almost completely in terms of the 30m/7-band data. The 10m/12-band data will simply force an increase in the required link transmission rates by a factor of approximately 15 (i.e., $(30/10)^2 \times (12/7)$), thereby increasing the cost advantage of a UOT satellite system over the other transmission alternatives.

In addition to the cost of the transmission facility, there are, in general, other criteria that could be considered during the selection process. Some of these have already been invoked earlier in this section. It is appropriate at this point to state these criteria in summary form and to indicate their applicability to the selection of the UOT transmission alternatives in the context of specific realizations of each of the three candidate classes of topology. This is done in Table 8-13. Discussion and comparison of the three classes of network topology is given in Section 11 subsequent to presentation of the results of a computer simulation of the topologies.

Table 8-13

Summary Results of Transmission Alte

TOPOLOGY CLASS	SPECIFIC REALIZATIONS OF TOPOLOGY CLASS	TRANSMISSION LINK CLASS	COMMON-CARRIER METERED SERVICE
Central Reception Central Preprocessing/ Distribution	White Sands (1)	Trunking Links	$
	White Sands or Sioux Falls or Goddard (Greenbelt)	Area Input Links	$,A
		Direct-to-User Links	$,A
Regional Reception Central Preprocessing/ Distribution	Sioux Falls & Fairbanks or Goldstone, Greenbelt & Fairbanks	Trunking Links	$,A
	Sioux Falls or Greenbelt	Area Input Links	$,A
		Direct-to-User Links	$,A
Regional Reception Regional Preprocessing/ Distribution	Sioux Falls & Fairbanks or Goldstone, Greenbelt & Fairbanks	Trunking Links (8)	$
	Sioux Falss & Fairbanks or Goldstone, Greenbelt & Fairbanks	Area Input Links	$,A
		Direct-to-User Links	$,A

(1) True central reception of CONUS (lower 48 plus Alaska) data requires the use of a Tracking & Data Relay satellite since no single location in either the lower 48 states or in Alaska is within view of the LERS for all LERS passes over CONUS. White Sands, NM, is currently being mentioned as the site of the primary ET for TDRS down link, although comments regarding this topology are not limited to this particular site.

(2) A 10/12 dissemination network could possibly support a user-owned satellite since, as stated in Section 11, the 10/12 data would require about three 40-Mbps transponders.

(3) As stated in note 1, a truly central-reception topology requires use of a TDRS. The TDRS ET would not be available for, nor would it be capable of (not being a tull-tracking terminal), transmitting through the LERS. A separate primary ET would be required for the up link.

(4) The TDRS could be used for trunking of either the 30/7 or the 10/12 data but would not, as presently configured, have the capability to handle the 10/12 raw data into White Sands without some further technology development.

(5) The cost of receive-only area-input-link or direct-to-user-link ET's for use with a LERS would be prohibitive since they would be required to acquire and track the LERS and to receive at bit rates approaching that of the raw data rate downlink into the primary ET's. Since an add-on transponder would have to be placed on the LERS to handle these links in the first place, it would be more cost effective to place the transponder on a geosynchronous satellite (e.g., SEOS).

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FOLDOUT FRAME)

Table 8-13

of Transmission Alternative Comparisons

LINK CLASS	COMMON-CARRIER METERED SERVICE	COMMON-CARRIER DEDICATED SERVICE	USER-OWNED LOS MICROWAVE	UOT / LEASED TRANSPONDER	UOT / ADD-ON TRANSPONDER	UOT/ USER-OWNED SATELLITE	LERS	TDRS
	TRANSMISSION ALTERNATIVES							
ks	$	$	$	*	*	$ (2)	$ (3)	A,R (4,6)
inks	$,A	$,A	$	*	*	$ (2)	$ (5,7)	A (6)
er Links	$,A	$,A	$	*	*	$ (2)	$ (5,7)	A (6)
ks	$,A	$,A	$	*	*	$ (2)	$,I (7)	A (6)
inks	$,A	$,A	$	*	*	$ (2)	$,I (5,7)	A (6)
er Links	$,A	$,A	$	*	*	$ (2)	$,I (5,7)	A (6)
ks (8)	$	$	$	*	*	$ (2)	$,I (7)	A (6)
inks	$,A	$,A	$	*	*	$ (2)	$,I (7)	A (6)
er Links	$,A	$,A	$	*	*	$ (2)	$,I (7)	A (6)

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(6) Scheduling problems might prevent use, especially for the 10/12 case with TDRS as presently configured. Barring this eventuality, the use of TDRS for dissemination of data would be no different, in concept, from the UOT satellite systems.

(7) Mutual viewing time of Fairbanks and Sioux Falls or Greenbelt or Goldstone is inadequate. However, even for a possible link between the central preprocessor (eg, Greenbelt) and the central distributor (e.g., Sioux Falls), the ET at the central distributor would have to have acquisition and full tracking capability and would be forced to receive at a rate equal to that on the raw data down link into the primary ET's. Since a transponder would have to be added to the LERS to handle this type of link, it would be less costly to add it, instead, to a synchronous satellite (e.g., SEOS).

(8) Only used between regional distributors, if required at all.

Transmission Alternative Symbol Definitions:

$ - high cost

A - (probably) not available

R - if available, higher risk

I - is a physical impossibility

* - chosen for further study

FOLDOUT FRAME

SECTION 9.0

DATA PROCESSING TECHNOLOGY/COSTS

9.1 Introduction.

The purposes of this section are:

1. to define a preprocessing structure for simulation
2. to estimate ground processing development requirements in support of the higher data and throughput rates implied by improved spatial resolution.

The assumptions implicit in this section are:

1. All data will be maintained in a digital-data base from reception to delivery to the user.
2. Users, through either a regional or a local facility, will have computational ability to perform user-specific analysis.
3. Users will be capable of 'cosmetic' corrections such as insertion for line drop-outs. Such corrections, particularly involving visual inspection, will not be required in a preprocessing facility. Furthermore, stripping, so troublesome in current LANDSAT imagery, will be eliminated by 1985 by proper design of the sensor calibration including nonlinear calibration curves.
4. In order to support users with sophisticated computational ability, all calibration, attitude, orbital parameters (best estimate), and time data will be maintained in the data stream. Transformation to user-unique coordinate systems will be performed by the user. This assumption seems reasonable in view of the range of coordinate systems now in practice and the likely availability of automatic hardware and software for coordinate transformation by 1985.

9.2 Requirements.

This section sets forth the processing requirements in terms of type of functions to be performed, their sequential constraints, and the timing limits associated with the timeliness requirements suggested in Section 5.0.

9.2.1 Timing Requirements: Timing requirements for data preprocessing and transmission are first derived for the case of six satellite passes over CONUS in a single day. These are based on two orbiting satellites phased such that LANDSAT paths 11, 29, and 47 are traversed by one satellite and paths 15, 33, and 51 by the other. For a cloud-free day, these represent about 4690 n.mi or approximately 47 scenes.

For a 30m/7-band case, a single scene represents 2.134×10^9 bits. A 10m/12-band scene correspondingly has 1.9207×10^{10} bits. Given the six passes in a single day consisting of

47 scenes and allowing for 10% overhead, the toal number of bits per day for each case is 1.1×10^{11} and 9.93×10^{11}, respectively.

Currently, the NASA NDPF processes about 200 scenes per day which accommodates both the domestic and the international requirements. For 200 scenes, the corresponding daily data loads would be 5.696×10^{11} bits (30m/7 band) and 3.84×10^{12} bits (10m/12 band) per day.

Table 9-1 lists the minimum throughput rates for 30m/7-band, and 10m/12-band data to preprocess and disseminate 47 and 200 scenes daily. These rates are given for serial data (parallel by band and parallel by detector data), and for 8-, 16- and 24-hour preprocessing and dissemination time constraints.

Table 9-1

Minimum Throughput Rates (bits/sec)

	47 Scenes		200 Scenes	
	30m	10m	30m	10m
Serial Data				
8 Hrs.	3.82×10^6	3.45×10^7	1.63×10^7	1.47×10^8
16 "	1.91×10^6	1.73×10^7	8.13×10	7.36×10^7
24 "	1.27×10^6	1.15×10^7	5.4×10^6	4.89×10^7
Band Parallel				
8 Hrs.	5.46×10^5	2.88×10^6	2.3×10^6	1.23×10^7
16 "	2.73×10^5	1.44×10^6	1.16×10^6	6.13×10^6
24 "	1.82×10^5	9.59×10^5	7.74×10^5	4.08×10^6
Detector Parallel				
8 Hrs.	3.64×10^4	3.6×10^3	1.55×10^5	1.53×10^4
16 "	1.8×10^4	1.8×10^3	7.66×10^4	7.6×10^3
24 "	1.2×10^4	1.2×10^3	5.1×10^4	5.1×10^3

The data from the foregoing table serves as a guideline for minimum throughput rates throughout the network. It should be noted that parallel processing of 800 detectors per band is unlikely due to cost factors. The band-parallel rates should, therefore, serve as an estimate for the 10m case.

Another means of identifying the timing requirements is to use an equivalent preprocessing time per pixel. Figure 9-1 presents the preprocessing time per scene in terms of spatial resolution, number of spectral bands, and preprocessing time per pixel. By way of comparison, current preprocessing time per pixel is about 3.75 microseconds per pixel [1]. By inspection of Figure 9-1, 10m/12-band data would require pixel throughput rates less than 0.25 microseconds per pixel which currently is a severe technological constraint.

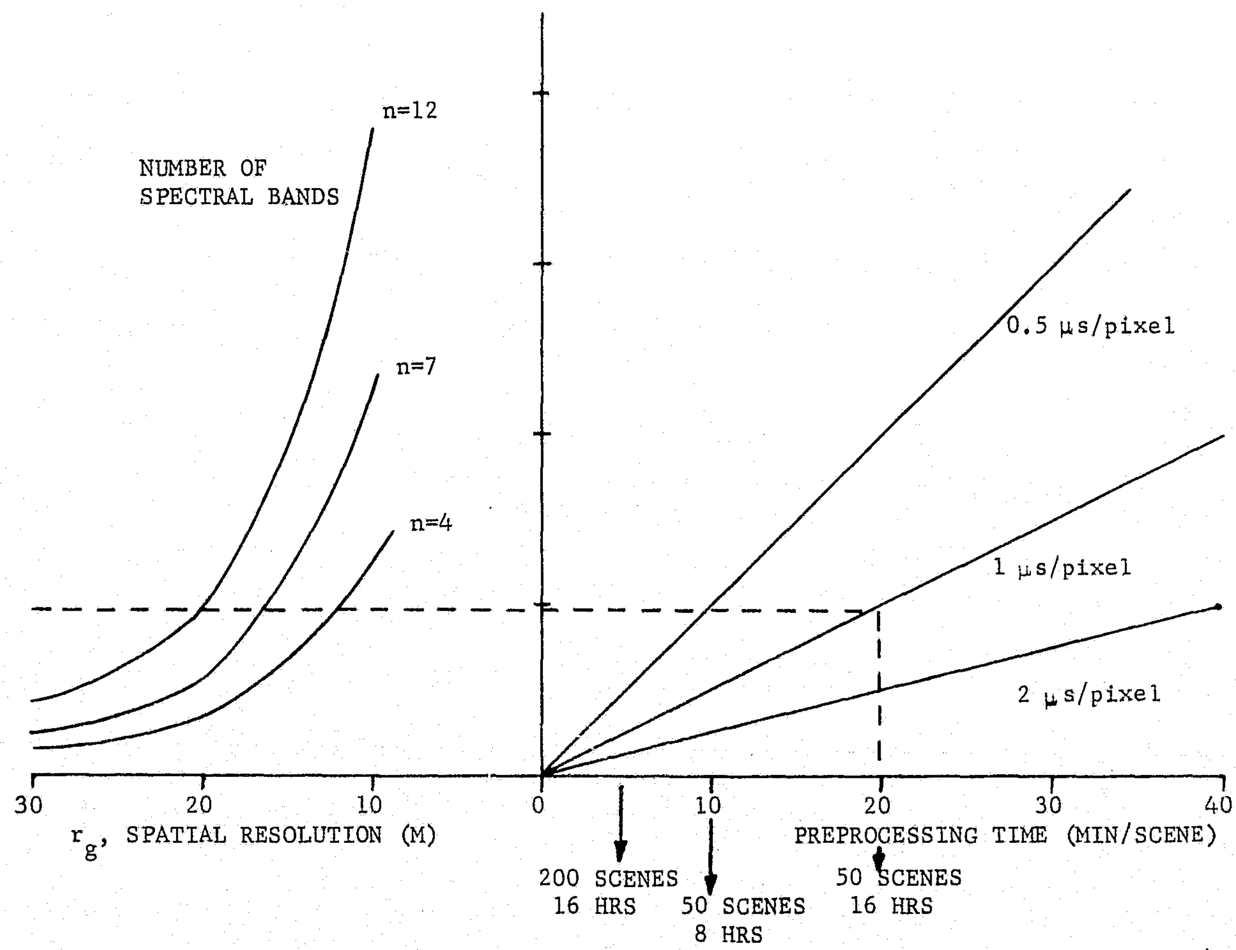


Figure 9-1. Preprocessing Time Requirements

9.2.2. Preprocessing Functions: In this report, preprocessing refers to those functions which are performed prior to data delivery to the user. The specific preprocessing functions considered were:

- Record and playback
- Reformatting
- Address insertion
- Channel redundancy removal
- Quick-look data extraction
- Cloud-cover extraction
- Radiometric correction
- Geometric correction
- Cloud-cover assessment
- Archival storage
- Data routing

Each of the above is described in the following text.

9.2.2.1 Record and Playback: This function refers to the initial recording during reception of the satellite signal. At least three techniques are possible: direct record, demultiplexing and record on parallel tracks, or serial-to-parallel conversion and record on parallel tracks. The bulk data rates assumed for the polar orbiters range from 101.3 Mbps to 1552.4 Mbps. These two extremes were used as criteria for 30m and 10m data, respectively.

The recording requirements are established by the bulk data rate, the maximum satellite pass time, and the modulation technique. For the polar orbiter assumptions, this translates to direct-record rates between 10^8 and 1.6×10^9 bits per second. For quadrature phase shift keying (QPSK) modulation and assuming preservation of parallel data streams, these reduce by half to 5×10^7 and 8×10^8 bits per second. For CONUS reception only, the maximum pass time will not exceed 7 minutes. However, if data recorded in the satellite over foreign territory is included, then reception and record time would be increased. Maximum reception time between 10-degree elevation angles is about 15 minutes.

Table 9-2 lists data rates and capacity requirements for the two data cases.

Table 9-2

Data Rates & Volumes - 30m/7-band, 10m/12-band

	30m	10m		
	Direct	Direct	QPSK (2 Data Streams)	8PSK (4 Data Streams)
Data Rate (Mbps)	102	1600	800	400
Data Volume (bits) (CONUS single pass)	4.28×10^{10}	6.72×10^{11}		
Data Volume (bits) (10^o elev. angle single pass)	9.18×10^{10}	1.44×10^{12}		

Playback requirements present another constraint. In order to avoid significant buffering, it is desirable to match the playback rate to the transmission rate (for regional reception) or the throughput rate and intermediate storage capacity (at the central processor). For regional reception, the trunking data rate R_t, therefore imposes a requirement on the ratio of record speed to playback speed, r. This is given in Figure 9-2. The importance of the playback speed becomes apparent during consideration of real-time processes such as quick-look extraction.

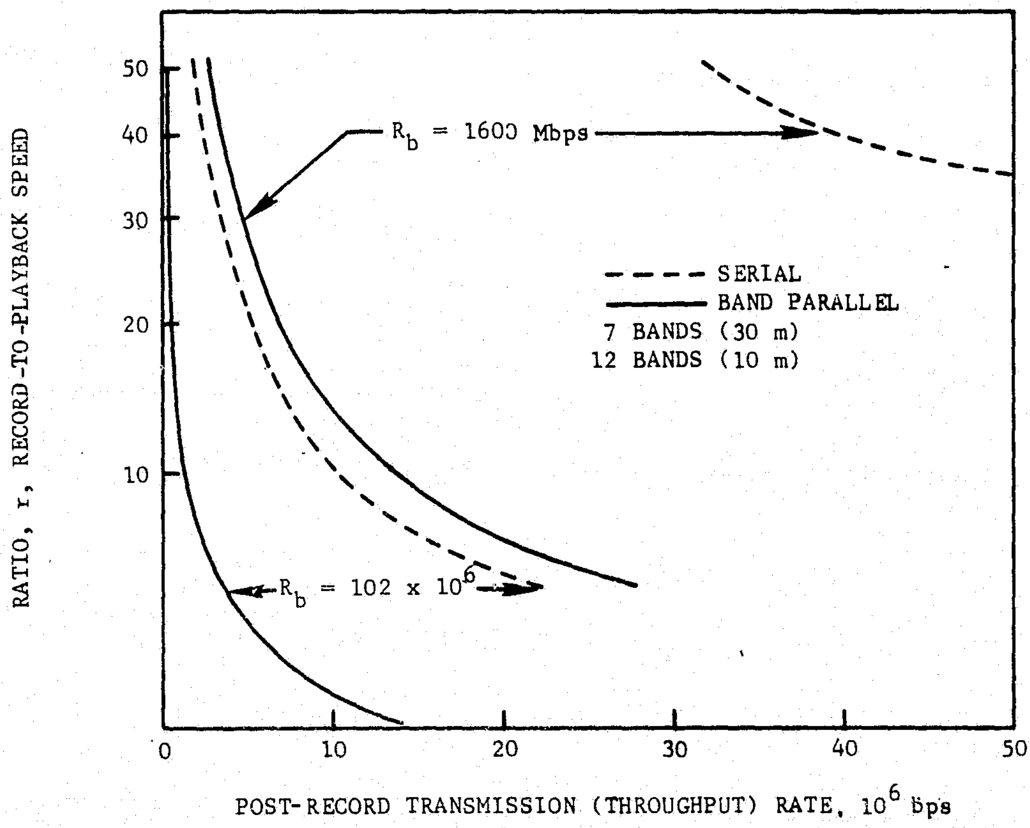


Figure 9-2. Data Rate Versus Record-to-Playback Ratio

Existing technology is adequate to record the 30m/7-band data (102 Mbps). This can be accomplished by parallel-to-serial conversion and record on a multi-track instrumentation tape recorder. For the case of a 32-track recorder of which 28 tracks are dedicated to data, an input serial data rate of 102 Mbps would require a record rate of 3.64 Mpbs per track. At a record rate of 120 inches per second, a packing density of about 30.3 kbits per inch per track is required. Packing densities of 33 kbits per inch per track are now commonly available. A standard 9200-foot tape recording at 120 inches per second provides about 15.3 minutes of record time which exceeds the maximum time of a single satellite pass over CONUS by about 8 minutes. This excess could accommodate recorded (international) data.

Other systems now under development include the RCA High Density Multi-track Recorder (HDMR) [2] which uses 142 tracks recording at 108 inches per second; thus accommodating serial data rates up to 240 Mbps. This unit, however, is not now designed for a lower playback speed which might necessitate an additional record-and-playback operation.

Current magnetic-tape-recorder technology will allow recording of bulk data rates up to approximately 130 Mbps. Development projects such as the RCA high-density multitrack recorder would extend this capability to 240 Mbps within a decade. This recorder, which could be available as either a flight- or ground-based unit, is expected to be available by 1979 at a cost estimated in the vicinity of $400,000. One design goal of this unit is to achieve a bit packing density of 1.2 to 2.0 x 10^6 bits per square inch which compares with 0.92 x 10^6 bpi^2 for a standard IRIG 28-track recorder.

Optical recording appears to be the preferred technology for higher rates. Development technology using hologram recording is now demonstrating 600 Mbps record rates on 35-mm film media. This development, by Harris Radiation Inc., has been estimated to be extendable [3] to 1.2- to 1.8-gigabit-per-second rates in the next 5 to 10 years. Currently, film speeds are at 12 feet per second and demonstration has been performed on only 250 feet of film (20.8 secs). The design goal is to achieve record times of 7 to 9 minutes which would be roughly compatible with a single polar-orbiter pass.

The technological constraint for gigabit-data-rate recording also applies to the film processing cycle. Currently, film processing requires about 60 times the record time which would be excessive for a rapid data dissemination network. For example, a 10-minute pass would require 10 hours processing time. Processing speed would be one area of required technological development if timely (24 hr) data delivery is coupled with increased resolution below 30m.

Another approach to the high-data-rate bulk recording is to take advantage of modulation schemes such as multi-phase shift keying that preserves inherent timing; thus, avoiding synchronization problems with parallel recording on different recorders. For example, QPSK modulation allows a reduction by a factor of two in the bulk data rate.

9.2.2.2 <u>Reformatting</u>: With digital processing, it is preferable to work with data in a line-by-line format with each spectral band and detector as a separate portion of the data stream. Furthermore, the data format throughout the processing sequence should be compatible thus allowing for common control signals. In addition, if the quick-look data format is common to the preprocessed data format, a common frame synchronizer at the user facility would suffice for both data types. While there are numerous formatting techniques, the procedures described in the following sections were used to establish an estimate of preprocessing requirements.

Formatting must accommodate each detector per band and each band per line. A mechanical scanner consists of some number of contiguous detectors for each spectral band. This number, n, is dependent on, among other factors, the sensor spatial resolution, aperture, and detector type. For example, each spectral band of the four-channel MSS consists of six detectors that simultaneously scan cross-track to the orbital path. Point designs for the LANDSAT-D Thematic Mapper (TM) (30m resolution) have from 14 to 16 contiguous detectors. For this study, 15 detectors were assumed at 30m resolution. A 10m-sensor mechanical scanner will have a large number of detectors per band. This number can be estimated by extrapolating the Hughes TM design assuming the following factors constant:

N	apparent radiance at detectors
F	spatial frequency response
S/N	detector signal-to-noise ratio
e_o	optical efficiency
R	detector responsivity
e_s	scanner efficiency
n_d	detector noise factor
h	orbital altitude
W	swathwidth
D*	detectivity
f#	f-number

Given this assumption, then

$$\alpha^6 D^4 n = \text{constant, } K_1 \qquad \text{photodiode [4]}$$

$$\alpha^4 D^2 n = \text{constant, } K_2 \qquad \text{photoconductive and photomultiplier tube [4]}$$

where

α = sensor instantaneous field of view

D = sensor aperture

n = number of parallel detectors

Figure 9-3 is a plot of D versus n for a 10m ground resolution at an altitude of 920 n.mi. Obviously, the number of parallel detectors per channel is dependent on the aperture which, in turn, is constrained by system weight and volume. A range from 300 to 800 detectors might be expected to indicate the number of parallel detectors for 10m resolution.

Each data point can be identified by a pixel, detector, and spectral band number. Data derived in the satellite will be on an instantaneous basis; that is, all data will be collected by band and by detector for each pixel thus the total data stream could be described as three summations:

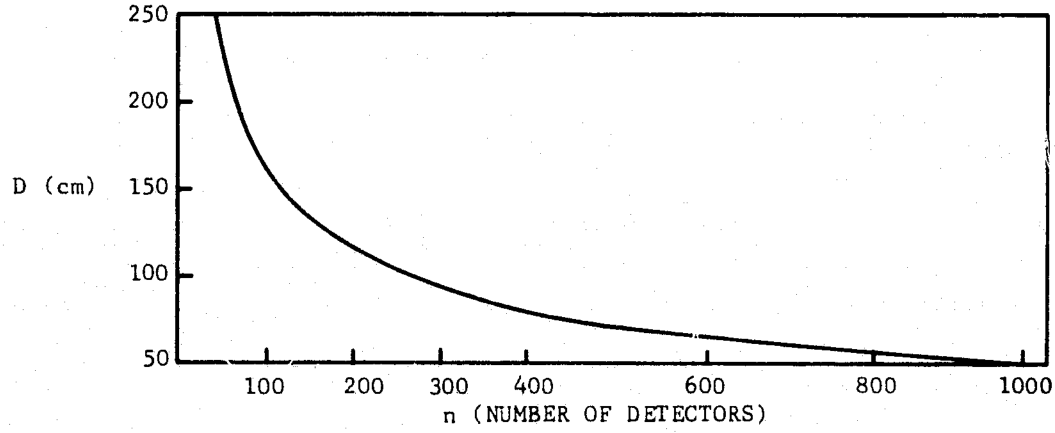


Figure 9-3. Number of Detectors, n, versus Sensor Equivalent Aperture, $D(r_g = 10$ meters; PMT and Photoconductive)

$$\text{Data} = \sum_{r=1}^{\ell} \sum_{q=1}^{m} \sum_{p=1}^{n} \quad \text{detectors}_p, \quad \text{band}_q, \quad \text{pixels}_r$$

the desired format would be:

$$\text{Data} = \sum_{q=1}^{m} \sum_{p=1}^{n} \sum_{r=1}^{\ell} \quad \text{pixels}_r, \quad \text{detectors}_p, \quad \text{band}_q$$

The following values are assumptions of this study:

		30m/7-band	10m/12-band
n	= number of parallel sensors	15	800
m	= number of bands	7	12
ℓ	= number of pixels per line	6173	18520

Given the notation (d_i, b_i, p_k) to identify each data point where d represents the detector, b the band, and p the pixel, the typical data input sequence (ignoring overhead data) to a regional terminal would be:

$$\left.\begin{array}{lcl} (d_1\ b_1\ p_1)\ (d_2\ b_1\ p_1) & \cdots\cdots & (d_n\ b_1\ p_1) \\ \vdots & & \vdots \\ (d_1\ b_m\ p_1) & & (d_n\ b_m\ p_1) \end{array}\right\} \text{data for pixel 1}$$

$$\vdots$$

$$\left.\begin{array}{lcl} (d_1\ b_1\ p_\ell) & & (d_n\ b_1\ p_\ell) \\ \vdots & & \vdots \\ (d_1\ b_m\ p_\ell) & & (d_n\ b_m\ p_\ell) \end{array}\right\} \text{data for pixel } \ell$$

Reformatting would consist of inserting the proper addresses or documentation words and rearranging the data sequence to:

$$\left.\begin{array}{ccc} (p_1\ d_1\ b_1) & \cdots\cdots & (p_\ell\ d_1\ b_1) \\ \vdots & & \vdots \\ (p_1\ d_n\ b_1) & \cdots\cdots & (p_\ell\ d_n\ b_1) \end{array}\right\} \text{data for n detectors along one scan of band 1}$$

$$\vdots \qquad\qquad \vdots$$

$$\left.\begin{array}{ccc} (p_1\ d_1\ b_m) & \cdots\cdots & (p_\ell\ d_1\ b_m) \\ \vdots & & \vdots \\ (p_1\ d_n\ b_m) & \cdots\cdots & (p_\ell\ d_n\ b_m) \end{array}\right\} \text{data for n detectors along one scan of band m}$$

In this instance, the reformatted sequence would be:

$$\begin{array}{lcl} \text{Word 1, word } (nm+1) & \cdots\cdots & \text{word } [(\ell-1)mn+1] \\ \text{Word 2, word } (nm+2) & \cdots\cdots & \text{word } [(\ell-1)mn+2] \\ \vdots & & \vdots \\ \text{Word } mn\text{, word } 2mn\text{,} & \cdots\cdots & \text{word } mn\ell \end{array}$$

Such reformatting could be achieved by scan line. That is, during playback, each line would be loaded into a buffer and read out in the desired sequence. During that read operation, an address could be inserted for each detector line. Thus, for the 30m case consisting of 7 (bands) times 15 (detectors per band) a seven-bit word would be required for detector identification. A 600-detector-per-band 10m design with 12 bands has 7200 detectors, thus requires a 13-bit word for identification.

Buffer requirements to achieve this reformatting depend on the input and output data rates. An 'on-the-fly' operation (that is, equal input and output rates) would require a storage capacity of 2 lines or 2 $(\ell -1)mn$ words. For the 30m case (7 bands, 15 detectors), this would be about 691 kilowords; for the 10m example (12 bands, 600 detectors), about 266 megawords.

9.2.2.3 Address Insertion: The handling of high-speed digital data is greatly facilitated by the presence of synchronization and identification words that provide the ability to perform real-time operations on any line in the data stream and to protect against data loss associated with data drop-outs. As an example, identification words could indicate:

Platform source	Scan number
Time (resolution to period of one scan line)	Detector number Swath number
Spectral band	Nadir latitude, longitude identification
Resolution	

As the identification data is either known a priori or by word counts in the primary data stream, address insertion could be accomplished with a computer that loads an address buffer. Synchronization insertion may or may not be required, depending on the satellite data format. If required, a pseudonoise (PN) sequence could be inserted easily in the address buffer. In either case, approximately 500 8-bit words for identification and synchronization would be a sufficient size for the address buffer.

Both reformatting and address insertion could be performed during playback. This would allow at least seven minutes (record time) for a computer to set the read sequence (if variable) and to prepare an address table. Reformatting would be accomplished by loading a two-line buffer which is read out in the desired sequence. For 30m data, a single line consists of 6173 pixels times 7 bands times 15 detectors, plus overhead or 6.48 megabytes. For 10m data and 600 contiguous detectors, a single line would require 133-megabyte storage. This procedure implies a random-access-storage requirement ranging from about 13 megabytes (30m/7-bands) to 266 megabytes (10m/12-bands).

Address insertion for each scan line would have to be accomplished in the time required to load one scan line in the memory. This time is dependent on the record-to-playback ratio as well as the data structure; i.e., band parallel or serial (see Figure 9-2). Assuming 500 words are adequate for an address, the minimum transfer rate would be given by the expression:

$$R_t = \frac{500\ R_b}{rn}$$

where R_t = transfer rate (bytes/sec)

R_b = bulk data rate (bits/sec)

r = record-to-playback ratio

n = number of pixels per line

The number of pixels per line is given by the expression

$$n = \frac{185200\ m}{r_g}$$

where

m = samples per IFOV

r_g = spatial resolution

thus

$$R_t = \frac{5\ R_b\ r_g}{1852\ r\ m}$$

For reference, R_b was initially determined by the expression:

$$R_b = \frac{bn\ Sw\ N\ Vg}{er_g^{\ 2}}$$ see Section (3.2.3)

in which m (samples per IFOV) was assumed equal to one.

The required transfer rate (bytes/sec) for a serial data output from a tape recorder as a function of r_g and r are given in the following table:

R_t (megabytes/sec)	43.2	8.26	10.8	2.06	4.32	.826
r_g (meters)	10	30	10	30	10	30
r	1	1	4	4	10	10

For comparison, current minicomputer cycle times are in the order of 1 megacycle per second. This implies a required playback reduction of about 10 for 30m/7-band data and over 40 for 10m/12-band data if constrained by current cycle-time technology and the use of a minicomputer for address loading.

A further implication is the requirement to dedicate recorders to specific satellites or (in the case of 10m/12-band data) as many as 5 recorders per satellite in order to allow for read time prior to the next satellite pass record. Alternatively, a separate recorder could be used for playback (as would be the case for optical recording) with the attendant requirement for tape change.

9.2.2.4 <u>Channel Redundancy Removal</u>: As the spatial resolution of a mechanical scanner is reduced, a given cross-track swath, consisting of n parallel detectors, will exhibit a gap or overlap with the adjacent swath. This is due to variations of the orbital altitude which at a minimum, results from the earth's oblateness. This gap or overlap can be expressed as;

$$x = \Delta h n \alpha$$

where

x = overlap in meters

Δh = altitude variation in meters

n = number of parallel detectors

α = sensor instantaneous field of view in radians (IFOV)

Altitude variation over CONUS due to oblateness alone is about $\pm$ 4.5 kilometers. Using this figure, Table 9-3 gives the resulting swath overlap as a function of IFOV and n both in meters and percent of IFOV. These data were based on a 920-km orbit.

Table 9-3

Swath Overlap

r_g = 10 Meters		α = 11 mrad		
n	300	600	800	900
g	14.85	29.7	39.5	44.55
% IFOV	148.5	297	395	445.5

r_g = 30 Meters		α = 33 mrad	
n	9	15	20
g(m)	1.32	2.23	2.97
% IFOV	4.4	7.4	9.9

The driving parameter is n, which from Figure 9-3 is determined by the sensor design. Redundancy removal is not necessary for 30m/7-band.

Assuming that the sensor design will be set to produce an overwrite rather than a gap, this error can be corrected within an accuracy of one pixel simply by discarding redundant scan lines or swaths (4 lines for the 10m/12-band, 800-detector case). This correction can be accomplished from a priori information (satellite altitude as a function of time) or, more precisely, by data from an onboard altimeter merged in the primary data stream. In either case, the redundant lines can be removed by reading the scan line identification and discarding the scan lines indicated by the altitude information.

9.2.2.5 Quick-Look Extraction: If a quick-look data link to the users is established, then this data must be extracted (preferably as early as possible) for transmission. Quick-look data can consist of selected spectral bands, selected areas (sectors), or degraded resolution. The primary purpose of quick-look data is quality assessment particularly to allow the user to evaluate the extent of cloud cover and to generate or discontinue a data request or to prepare for subsequent data reception. Depending on the network configuration, this may reduce the preprocessing load. A secondary purpose is to review archival data for selection of preferred data sets.

Given proper data addresses, i.e., source identification, spectral band, scan number, etc., quick-look data extraction from the primary data sequence can be performed by reading each address and gating this data to a quick-look buffer.

Resolution degradation is accomplished easiest by pixel averaging and line skip. Current technology will allow this function to be performed at data rates up to 250 Mbps using conventional emitter-coupled logic. Thus, quick-look data extraction can be performed in real time after reformatting and address insertion.

Since some quick-look data may have multiple user demand, a two-stage extraction procedure is implied. Initially, the data set consisting of all quick-look data requested can be extracted from the primary data stream in real time. Quite probably, this extraction would be by band sets. After this step, parallel area, band, and resolution data sets would be extracted for each user. Buffering would then be necessary on each user channel prior to multiplexing, if necessary, and transmission. Alternatively, if user transmission is broadcast on a non-unique basis; i.e., users select desired data from a continuous data stream, then two-stage extraction, additional buffering, and multiplexing would not be required.

In the broadcast mode, the user terminal would, by pre-selected addresses or headings, automatically select the area of interest. The broadcast transmission would consist of one, or possibly two, spectral bands of reduced resolution both contributing to a lower data rate. Assuming one spectral band of 90m spatial resolution (roughly equivalent to current LANDSAT resolution) the resulting reduction in data volume relative to the primary data volume would be a factor of 972 (for 10m/12 bands) and 63 (for 30m/7 bands). For the user that requires only one scene (100 n.mi. by 100 n.mi.) in four bands, the data volume reduction relative to the data in a maximum-length swath (approximately 1400 n.mi.) over CONUS would be 30 and 17.5 for 10m/12-band data and 30m/7-band data, respectively. The implication is that, for users with antenna reception, the quick-look data rate could be less than the data rate for preprocessed data. Thus, the cost penalty imposed for reception of quick-look data would be, at most, the cost of a receiver and recorder. However, if quick-look data were broadcast at the same data rate as the preprocessed data, the user would suffer no cost penalty for its reception.

9.2.2.6 Cloud-Cover Extraction: Synchronous meteorological satellites are now providing virtually continuous daytime data on cloud cover within resolutions of 1 km (nadir). This data can be used, as is now the practice, to reduce satellite transmission over areas of heavy cloud cover. Alternatively, cloud-contaminated data can be eliminated on the ground by discarding those scan lines associated with known cloud cover by reading the scan line address. Again, this correction can be performed in real-time given properly registered auxiliary meteorological data.

9.2.2.7 Cloud-Cover Assessment: Current user requests for LANDSAT data specify acceptable cloud-cover percentages. Typical requests allow 10-20% cloud cover although the correlation of cloud cover to area of interest may allow much higher percentages. This factor is, of course, the prime advantage of a quick-look link or even a dissemination network that rapidly provides all data so that the user can perform his or her own assessment. Nevertheless, a cloud-cover assessment will likely be necessary prior to archives to support conventional data distribution.

Cloud-cover assessment has been performed on an interactive basis involving human judgment. By 1985, automatic cloud-cover assessment should be operational.

Whichever, human interactive or automatic, this function can be performed 'off-line' under the reasoning that data rapidly disseminated to the user need not be annotated with a cloud-cover percentage. The user can make the decision of data quality with either quick-look or the actual data.

9.2.2.8 Radiometric Correction: As each detector exhibits different spectral response and sensitivity, the radiometric values must be adjusted to eliminate this error source. This can be done either by using the in-flight calibration data to adjust coefficients of linear equations or by adjusting the means and standard deviations of all detector probability-density functions to be similar. The latter correction, which can be performed without auxiliary data, is based on the assumption that over large areas the probability-density functions should be the same.

For the network simulation in this study, the radiometric correction technique uses on-board calibration data. The specific algorithms used were taken from "A Study of Ground Data Handling Systems for Earth Resources Satellites," NASA JSC Contract NAS9-1261, Volume III, page 3-4. This procedure involves the following steps:

a. Calibration words for each line and detector are averaged, then smoothed by Kalman filtering by the relations

$$\overline{CH}_n = \overline{CH}_{n-1} + W_n \left(CH_n - \overline{CH}_{n-1}\right)$$

and

$$\overline{CH}_n = \overline{CL}_{n-1} + W_n \left(CL_n - CL_{n-1}\right)$$

where

$\overline{CH}_n, \overline{CL}_n$ = high, low calibration words for n^{th} line

CH_n, CL_n = high, low calibration word averages for n^{th} line

W_n = Kalman weight

b. The dynamic offset, given by $\overline{CL}_n$, is subtracted.

c. Using a table look-up procedure, sensor nonlinearities and scan-angle dependent errors are corrected. This correction requires 256 (for eight-bit words) addresses per table and some number of tables, typically 10, per scan line for each detector. Thus, for the 30m/7-band case, a memory of 26.88 kbytes are required. For the 10m/12-band case, and 600 detectors per band, 18.43-megabyte storage is required.

d. System gain variations are corrected by the following relationship

$$\bar{C}_{ij} = \overline{\overline{CL}} + \frac{\overline{\overline{CH}} - \overline{\overline{CL}}}{\overline{CH}_i - \overline{CL}_i} C_{ij}$$

where C_{ij} = pixel value (i^{th} line, j^{th} pixel)

$\overline{CH}_i$, $\overline{CL}_i$ = high, low filtered calibration words (i^{th} line)

$\overline{\overline{CH}}_i$ $\overline{\overline{CL}}_i$ = long-term high, low filtered calibration words

$\bar{C}_{ij}$ = corrected pixel value

The radiometric correction described previously will not correct for scene-dependent radiometric distortions; that is, detector relative responses that differ for saturated and unsaturated scenes or for detector hysteresis. This type of distortion may be corrected by convolution filtering.

9.2.2.9 Geometric Correction: Geometric correction is the time-consuming preprocessing function. Geometric distortions can arise from several factors including eastward displacement of scan lines due to the earth's rotation, earth curvature, satellite attitude changes, and altitude variations affecting the image scale. In addition, parallax distortion may arise during the comparison of two images, particularly when viewing an overlap region from adjacent passes.

Distortion due to the earth's rotation can be corrected by displacement of each line with an additional correction of the aspect ratio of each pixel. This correction, which is a function of latitude, can be performed using a priori information. Other distortions require some means of resampling the distorted input image to new locations in the corrected output image. The density values in the output image are recomputed by interpolation of some set of neighboring pixels in the input image. Various techniques have been implemented to perform this function. The first requirement is to locate the pixels in the input image to be used for interpolation. This can be done by referencing to a precision-corrected image or by comparison of 'ground control points' (GCP's) in the image to the correct GCP location from a master file. Typically, 10 GCP's are required for each scene. Improved satellite jitter performance may reduce the number of required GCP's. The resulting displacement can be used to derive, as by a least-squares fit, the nearest neighbor pixels in the input image to a given pixel in the output image. Various techniques such as a simple nearest neighbor relocation, bilinear interpolation, or the TRW cubic convolution can then be used to resample the density value of the corrected pixel. These techniques differ as to the number of nearest neighbors employed for each interpolation.

This study was not directed toward an evaluation of geometric correction techniques nor was the simulation based on a particular technique. The simulation of geometric correction is discussed in Section 9.3.

9.2.2.10 Archival Storage: It was assumed that archival storage would occur after geometric correction. As this involves 'off-line' processing, no time loss is associated with the dissemination of current data. It should be noted that the address insertion would facilitate data search for archival requests as each scan line would contain satellite source, time, and latitude-longitude coordinates (nadir). Thus, record keeping would be reduced to a table identifying data on each tape. Digital logic on the output of each tape recorder could allow for automatic identification and selection of the appropriate data sets requested from archives.

9.2.2.11 Data Routing: Data routing consists of selecting data sets for specific users. If a broadcast mode is used to disseminate data to the user, data routing consists simply of merging archival data requests with the pipeline data flow. If, however, a unique mesage is transmited to each user, then the appropriate data sets must be selected and stored prior to user transmission.

The routing function could be accomplished by data sectorizers that select areas by line count, pixel count, and spectral band in real time. Each sectorizer would be dedicated to a single user or to a set of users that require non-overlapping data. A user-unique address would be inserted at the output of each sectorizer. This function could be performed in real time at the output of the geometric correction. A hierarchy of sectorizers would select the appropriate data sets as indicated by a controller and route them to buffer storage. These data would then be routed to separate transmission links or multiplexed on a single link as dictated by the transmission scheme. Buffer storage could be minimized by the selection of a data transmission rate roughly equivalent to the combined throughput rate at the routing output.

9.3 Baseline Preprocessing Facility

The purpose of this section is to configure a baseline preprocessing facility that can be used to support:

a. cost differential estimates between regional and centralized preprocessing, and
b. verification of throughput rates indicated by the simulation.

Unlike transmission link costs, processing costs cannot be accurately related to throughput rates without reviewing specific hardware requirements. As the required throughput rate is increased, different hardware items become bottlenecks, and, if possible, must be duplicated. Often, a redesign of the data handling approach may circumvent a bottleneck. Thus, data processing schemes tend to become deterministic based on assumed requirements.

In order to generate cost estimates for preprocessing, a baseline configuration, as reported in this section, was configured. As noted in Section 9.2, several technology constraints

prevent implementation of a rapid turn-around system for 10m/12-band data loads. These constraints include recording, playback, and high-speed resampling processing at 0.25 microseconds or faster per pixel. Therefore, this baseline was configured for 30m/7-band data.

A generalized functional block diagram of the baseline facility is depicted in Figure 9-4. The primary characteristic of this system is the use of three dedicated controllers that maintain functional control over specialized hardware, provide working memories, perform calculations, and transfer auxiliary data through the system. All data remains in the digital domain, except during display, and all operations are digital. For purposes of presentation, this facility is divided into four subsystems; radio frequency, data handling, correction processing, and user transmission.

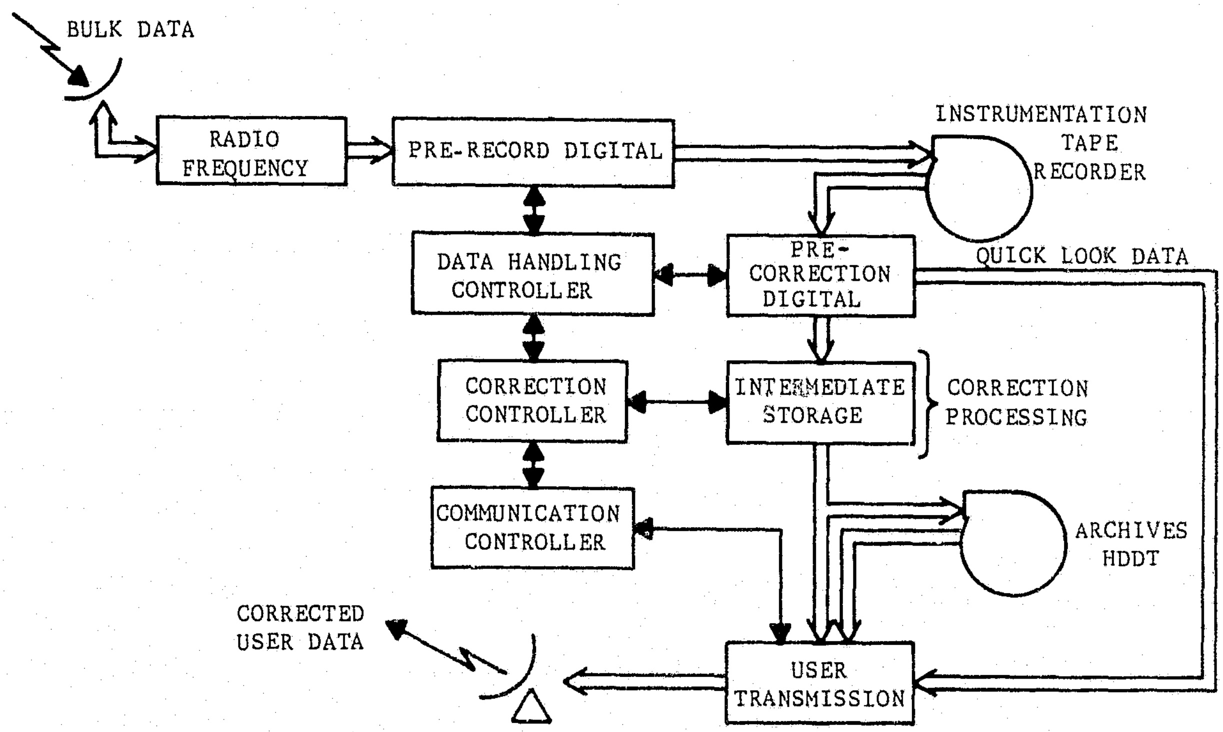


Figure 9-4. Generalized Functional Block Diagram of Baseline Central Facility

It is assumed that the satellite/sensor design will provide all calibration attitude, mirror scan, and time information in the primary data stream. This data is read and is transferred to the data handling controller prior to recording. During recording (7 to 17 minutes), this data is tranferred to the appropriate controller or specialized processor so that radiometric look-up tables, bulk data GCP locations, attitude error estimates, and header information is calculated and loaded into registers prior to playback. In this manner, the record time is usefully employed.

Immediately upon playback, the bulk data is reformatted and each scan line and all detector lines within a scan line are identified in a header address. Thus, at any time during subsequent operations, the data identity can be determined for each scan line. Similarly, certain functional hardware, such as quick-look data extraction, can use this header information to perform the desired operations. This type of data structure also allows the operator to identify data at various points in the flow. Furthermore, user reception is facilitated by the availability of header information to automatically extract user-desired data sets.

In this configuration, data is played back band parallel to an intermediate disk storage. During this storage, GCP matching and computation of the mapping function is performed. Upon completion of this process, data can be resampled at rates in the vicinity of 1 Mbyte/sec (8 Mbits/sec) per spectral band. The general data rate requirements for this facility are:

Bulk data rate (Mbps)	105
Scan time (ms) (7 bands, 15 parallel detectors per band, 6.46-km/sec ground track velocity)	70
Band parallel data rate (Mbps)	15

9.3.1 Radio Frequency Subsystem: The radio frequency subsystem consists of those components from the antenna through the receiver/demodulator; the output of which is a digital signal. The equipment (consisting of antenna feed, preamplifier, receiver, demodulator, and antenna control unit) is shown in Figure 9-5.

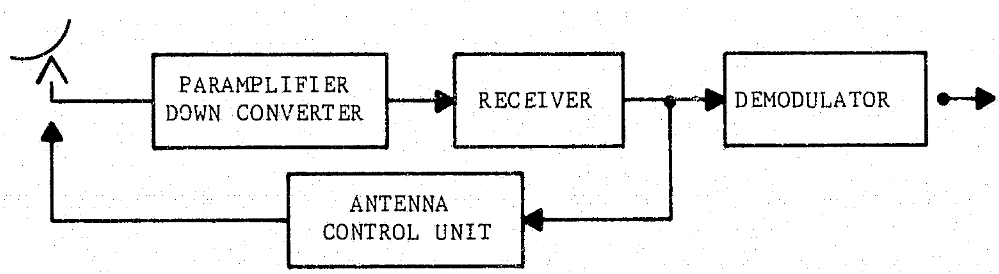


Figure 9-5. Central Facility Radio Frequency Subsystem

The bulk data (ERS to ground) link requirements are presented in Section 7.0. In summary, the reception antenna is less than 5 meters in diameter and the required system noise temperature is 170°K. The satellite antenna exhibits a beamwidth of 2.5° at a diameter of 0.6 meters. A frequency of 14.5 GHz was assumed to derive the above values.

Several studies have been directed toward on-board data processing in the satellite. Given the availability of transmission technology, preprocessing, as defined in this report, seems best performed on the ground rather than on the satellite; a possible exception seems to be direct transmission to special users. However, preprocessing can be greatly simplified by merging attitude, scan-mirror position, time, and calibration data in the primary data stream. This process, up to 1 Gbps, is within existing technology of spaceborne multiplexers. Even at 1.6-Gbps data rates (10m/12 bands), this function can be implemented using QPSK modulation. It was, therefore, assumed that proper housekeeping data sets would be multiplexed on the primary data stream during each scan line.

All radio frequency equipment associated with reception of 105-Mbps data is either off-the-shelf or, at most, requires modification to existing designs. Candidate preamplifiers, down converters, receivers, and demodulators exist for this application.

9.3.2 Data Handling Subsystem: It was assumed that all data handling would be computer-controlled from reception to user dissemination. Figure 9-6 is a functional block diagram of pre-record and playback equipment up to the correction functions.

9.3.2.1 Pre-record Functions: The output of the subsystem (demodulator) will be some form of an NRZ digital signal. A bit synchronizer will establish bit clock. The next component, termed a digital interface, performs three primary functions. These are:

1. Read, store, and transfer to the controller requested attitude, calibration, etc., data in the primary data stream.
2. Generate line sync signals for each detector row in each spectral band.
3. Insert data headings, including best estimate of the trajectory on each scan line for archival storage.

Logic circuits to perform these functions have frequently been employed. The process of reading selected words from the data stream and transferring these to the data handling controller may be implemented in a manner as shown in Figure 9-7. As data is received, the sync detector searches the data to establish synchronization. When sync is detected, the bit clock counter and the word clock counter are reset to establish synchronization. The decoder examines the word clock counter to determine when appropriate data words (calibration, attitude, etc.) are present. The decoder provides start and stop points which span the length of the desired data words. During this period, the data is shifted into a shift register and is transferred to the computer bus with the transfer clock.

The data and clock outputs of the digital interface will be converted to parallel data streams for the tape-recorder track assignment. A special-purpose instrumentation tape recorder could be used for primary recording. As noted in Section 9.2.2.1, current technology is adequate to perform this function. The primary functions of the controller are listed in Table 9-4.

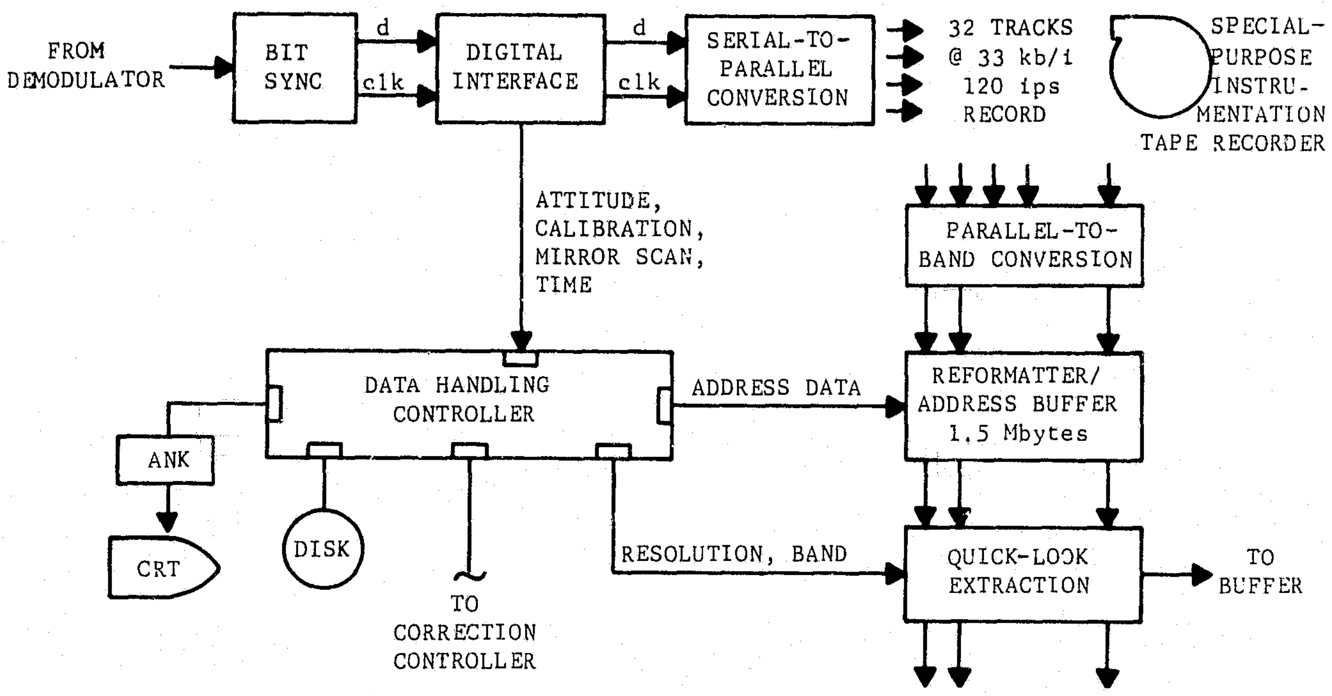


Figure 9-6. Central Facility Data Handling (Precorrection) Subsystem

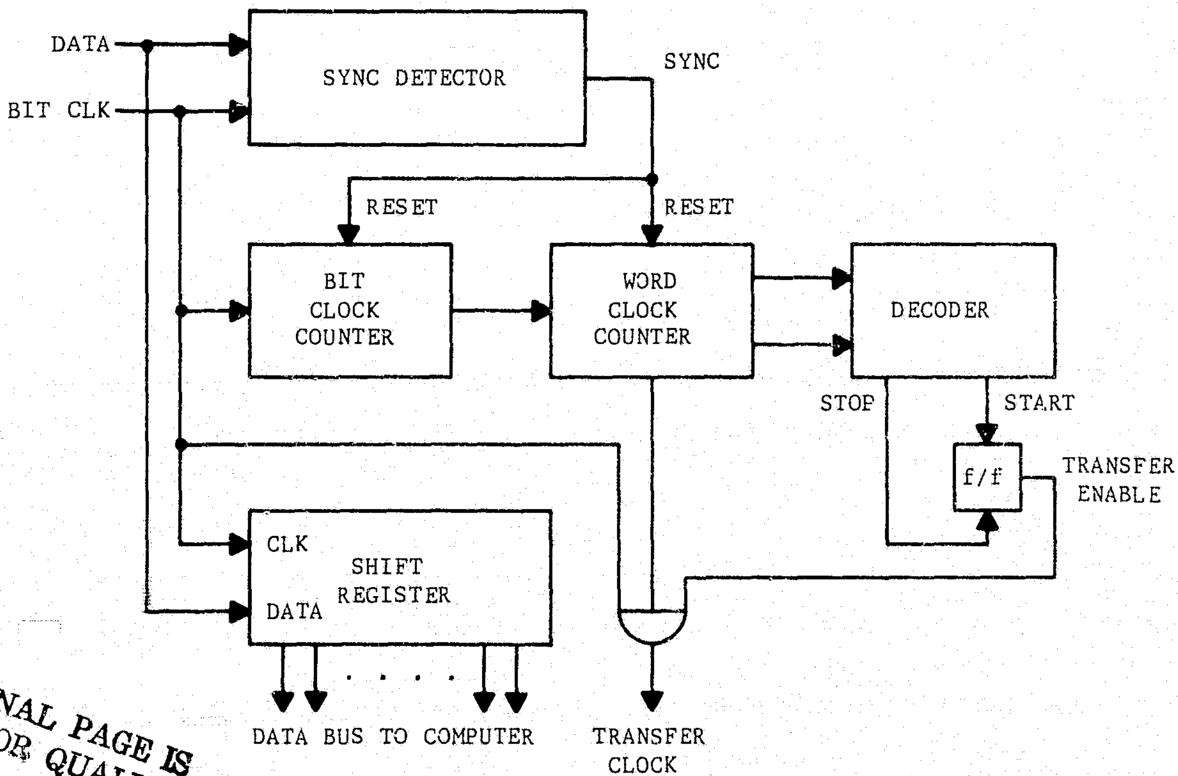


Figure 9-7. High-Speed Data Word Transfer to Computer

Table 9-4

Controller Functions

Function	Comment
1. Display data reception status (in-lock conditions, source, bit error rate, receiver S/N, etc., data identity)	Status data translated at digital interface and displayed on alpha numeric CRT.
2. Control record and playback search.	Exercised through digital interface.
3. Construct line addresses.	Loads address register during reformatting.
4. Select quick-look spectral-band resolution and sectors.	Pre-sets quick-look extraction hardware based on quick-look requests and transmission constraints.
5. Perform ephemeris update to drive antenna to next pass location.	Updates antenna control unit during transmission dead time.
6. Transfer attitude, mirror, scan, and time information to correction controller.	Attitude determination data and time extracted by digital interface and transferred to controller during reception.

No attempt was made to size the controller memory core or disk capacities. The computer minimum-cycle time is a requirement set by the data rate. Since the digital interface operates in real-time, the controller must be capable of responding to a protocol and accepting extracted data in the period of one scan line. Assuming 12 calibration words per detector and 30 words (time, mirror position, and attitude) per scan line, then 210 words would have to be transferred in 70 ms. This requires a maximum of 0.33 microseconds per word (packed two words to a byte) which exceeds current mini-computer specifications (1 ms) but is certainly within current technology. The general requirements for this controller imply that a medium-class minicomputer would be adequate for this function. Recording would be accomplished as described in Section 9.2.2.1.

9.3.2.2 Playback Functions: Playback data handling functions are defined as reformatting, parallel-to-band conversion, and quick-look extraction. Use of an instrumentation tape recorder will allow the playback rate to be adjusted. Depending on the system design, this rate can be critical in sizing subsequent storage. In this baseline configuration, the playback duration is limited by the capacity of mass storage disks (see Section 9.3.3).

Reformatting can be accomplished by loading a 2-line buffer and reading out in the desired sequence. For the assumed 30m/7-band case, this would require about 1.3×10^6 words (6173 pixels x 7 bands x 15 detectors x 2 lines). During this reformatting operation, the controller could insert additional heading information, such as nadir latitude/longitude, that requires calculation after data reception. Parallel-to-band conversion would be performed

in real-time; quick-look extraction can also be performed in real time. The data may be selected by spectral band and averaged over n pixels with n line-skips to provide a resolution reduction by a factor of n. Again, logic to perform this function is frequently employed. In addition, specific sectors can be extracted as desired. The sectorizer would be set by the controller which would review the quick-look requests and establish a master data set to be extracted. This function would not be necessary if a standard quick-look format is disseminated by a broadcast mode. Operational sectorizers now exist that perform similar extraction.

The quick-look data stream is a convenient source to provide a visual quality check. This could be performed most inexpensively by use of a scan converter to refresh and monitor.

9.3.3 Correction Subsystem: Correction processing consists of geometric and radiometric correction. In this baseline configuration, these functions are performed with a combination of a medium-size general-purpose computer, two dedicated microprogrammed processors, and a special-purpose array processor. A functional block diagram of this equipment is shown in Figure 9-8. As depicted, radiometric correction and GCP extraction are both performed on the fly. Both the look-up table and extraction logic (band, line start/stop, pixel start/stop) are loaded prior to playback by virtue of information extracted from the primary data stream during reception.

After GCP extraction, the primary data enters an intermediate storage consisting of seven (bad parallel) disks each of 300-Mbyte storage capacity. This intermediate storage provides capacity for 7 30m/7-band scenes. Thus, only seven scenes are transferred at a time. Once the mapping function has been calculated and an address table has been derived, a random-access working storage is loaded and resampled to the output image which is then loaded on one of two output disks. Specific details of this subsystem follow.

9.3.3.1 Radiometric Correction: The radiometric correction procedure suggested for this baseline uses calibration words imbedded in the primary data stream. The technique is identical to the procedure described in Section 9.2.2.8. Calibration words are read from the primary data stream and transferred through the data handling controller to the correction controller that averages and smooths each set of high and low calibration words for each detector. This process is performed during the record period. The high, low calibration averages are stored and inserted as constants into a band-parallel look-up table. As noted in Section 9.2.2.8, the look-up table would require 26.88-kbyte storage. Scene-dependent corrections based on detector statistics would require a delay (storage) not provided in this configuration. Such a correction, however, could be inserted after intermediate storage during the resampling process.

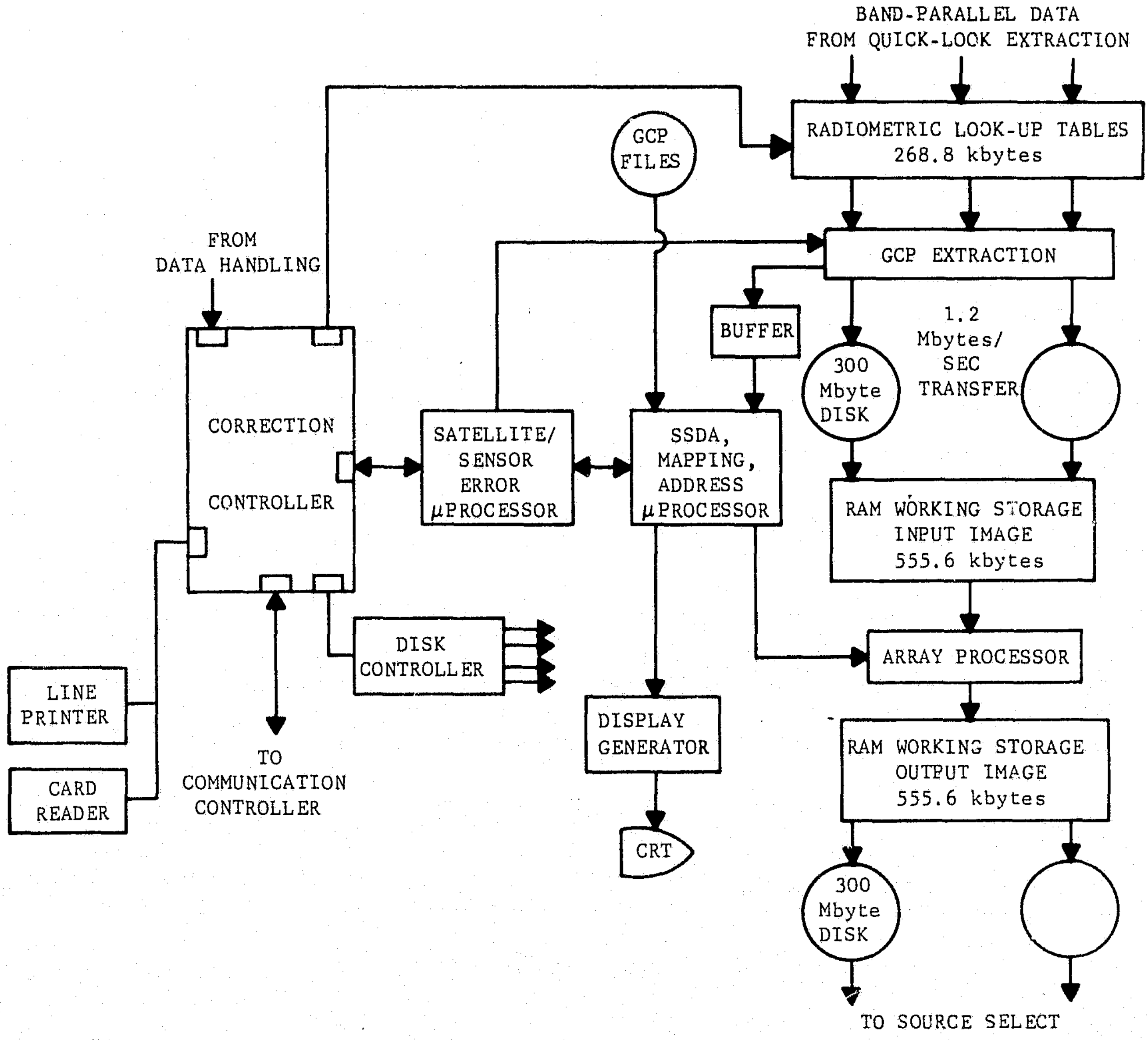


Figure 9-8. Baseline Correction Processing

9.3.3.2 GCP Extraction: GCP extraction logic is identical to the sectorizing logic. Given expected GCP window locations based on the microprocessor error model estimates, this process could be performed at data rates up to several hundred megabits per second. Since the data is band-parallel, simultaneous extraction from more than one band will only impact the buffer size with minor cost impact.

9.3.3.3 Geometric Correction: Geometric correction is the bottleneck in the preprocessing facility. Typically, this process involves the following steps:

1. Ground control point matching

2. Calculation of the mapping function and input/output pixel addresses
3. Image resampling

One study [5] estimates that using near-term technology, the corresponding times for correcting a 4-band LANDSAT scene for each of these steps is:

1. Ten (10) control points using automatic recognition - 4.5 min. (automatic recognition requires technological development)
2. Mapping function calculation - 0.5 min.
3. Image resampling using hard-wired cubic convolution algorithm and 3330-class disks - 3.5 mins.

If each step were sequential, these times would give a total geometric correction time of 8.5 minutes per LANDSAT scene. By comparison, the IBM system now under development for Goddard Space Flight Center is estimated to perform these functions in 2 minutes per LANDSAT scene using binomial interpolation in resampling. Scaling the latter time to a 30m/7-band scene indicates that current technology would require about 31.5 minutes.

A general description of the geometric correction technique is as follows. The extracted GCP windows are compared to reference GCP's using cross-correlation techniques or the IBM sequential simulation detection algorithm. This process is automatic and the time required to perform this task was estimated at 5 seconds per GCP.

The differences between observed and referenced GCP's are then used as feedback to correct the coefficients of the satellite/sensor error model. The error model is continuously updated with a Kalman state variable filter. This continuous updating will reduce GCP search times.

The GCP observed-to-reference differences are also used to evaluate the coefficients of two 5th-order bivariant polynomials which relate the output image grid to input image line/pixel coordinate system. The evaluation can be dramatically speeded up using special-purpose matrix-function integrated circuits. The time required to perform this mapping function calculation using a dedicated microprocessor was estimated at 4 minutes per scene. Finally, the input image is resampled at an estimated rate of 1 microsecond per pixel.

Using these estimates, a timeline was constructed to indicate the elapsed time from initial recording to completed user transmission based on a 7-scene transfer. Figure 9-9 illustrates this timeline by showing permissible overlaps in functions.

The preprocessing timeline was constructed in the following manner. First, a record time of 17 minutes was assumed. This overstates CONUS coverage and relates to horizon-to-horizon coverage. After recording, a 3-minute rewind period occurs. During this 20 minute period, auxiliary calculations are performed based on the data imbedded in the primary data stream.

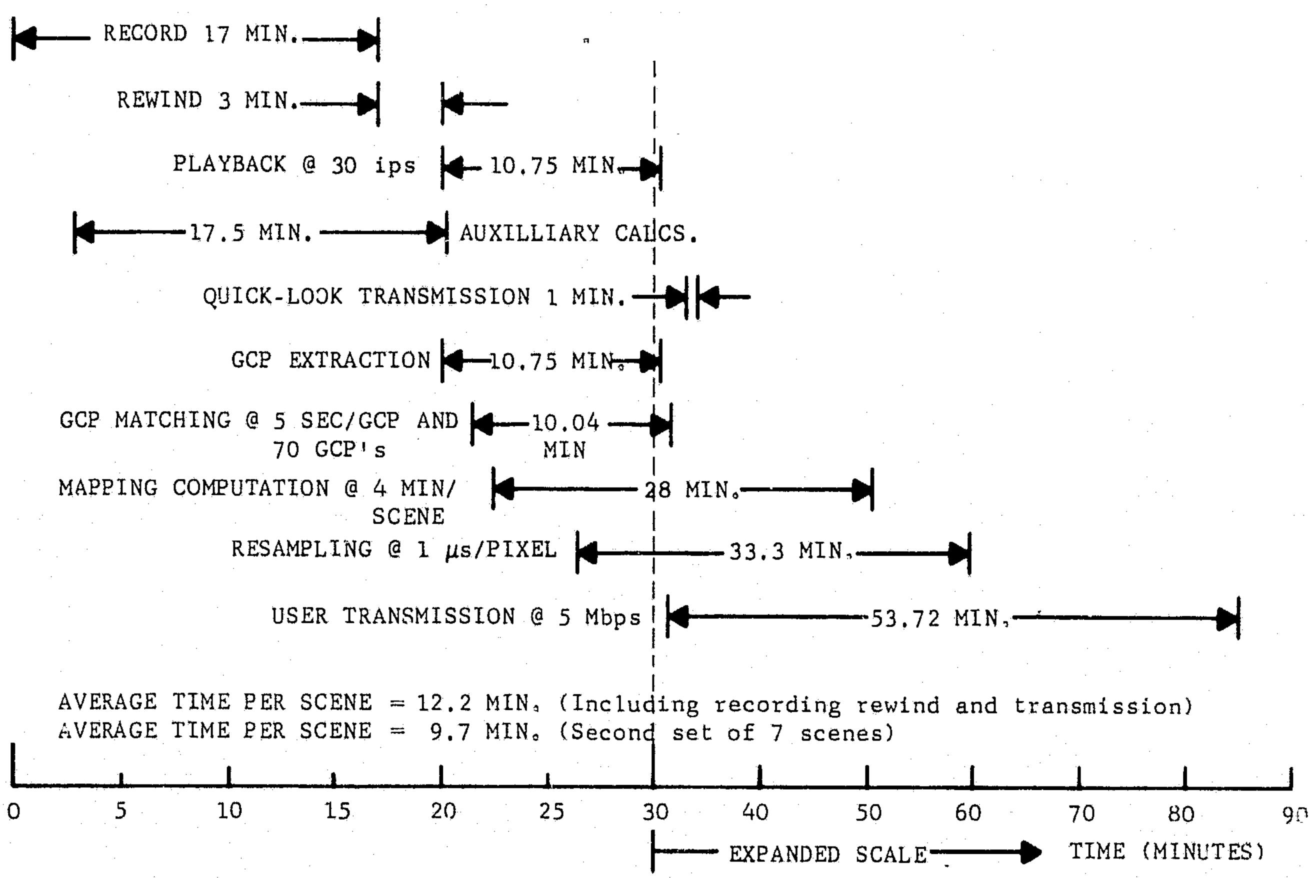


Figure 9-9. Preprocessing Timeline Estimate
(30m/7 Band) - 7 Scenes

Assuming a playback band parallel at 30 ips, a total of 10.75 minutes is required or about 1.54 minutes per scene.

If the desired GCP window were in the last portion of the first scene, GCP matching could not be started until 21.54 minutes from first reception. For one scene, this would require 0.833 minutes at 5 sec/GCP and 10 GCP's per scene or about 22.4 minutes total elapsed time. Similarly, GCP matching of the last scene (worst case) could not be accomplished until 31.58 minutes after initial reception.

The mapping computation (estimated at 4 minutes per scene) would require a total of 28 minutes for 7 scenes. This calculation for the first scene would not be completed until 26.4 minutes had elapsed. Since the playback rate per scene (1.54 minutes) is less than the estimated time for calculating the mapping function (4 minutes), the pacing time becomes the 28 minutes required for performing this calculation for 7 scenes. The total elapsed time for 7 scenes is now approximately 50.4 minutes.

The foregoing estimates are predicated on using one band for performing the mapping computation (correlation of distortion between bands). Additional bands per scene would increase this time estimate unless parallel processing were implemented.

Given 2.93×10^8 pixels per scene (30m/7 bands) and a resampling rate of 1 microsecond per pixel, approximately 4.88 minutes is required for resampling one scene. For the first scene (worst case) this would be completed after approximately 30.4 minutes total elapsed time. Again, since the resampling time per scene exceeds the mapping computation per scene, the total elapsed time for the last scene to be resampled is 25.5 minutes plus 34.2 minutes or 59.7 minutes.

Assuming 5 Mbps broadcast transmission to the users, each scene would require 7.8 minutes for transmission. The first scene would be transmitted after 38.1 minutes and the last scene after 85 minutes total elapsed time. The average time per scene, including recording and transmission, is about 12.2 minutes. However, it should be noted that the next seven scenes would not include the record time giving an average preprocessing time of 9.7 minutes per scene.

While this rudimentary timeline analysis fails to recognize certain operations, such as transfer times from the microprocessor(s) to the general-purpose computer memory and the allocation of operations between the CPU and microprocessor, the time pacing item is actually in the user dissemination transmission. Both the mapping computation and resampling times could be nearly doubled before significant increases in elapsed time would be experienced. This timeline does illustrate the time advantages of distributed processing and the need to balance throughput rates for sequential operations.

9.3.4 User Transmission Subsystem: In this configuration, three sources of data can be broadcast to users. These are: quick-look data, archival data and preprocessed pipeline data. These sources time share a single link and so their entry must be controlled. Figure 9-10 depicts generally the organization of this subsystem. The key element is a minicomputer that, through digital logic in the source select, controls the tape recorders and disks during read operations. This controller maintains a file on pipeline data location (transferred from the correction controller), quick-look data status and age (from the data handling controller via the correction controller), and archival data requests. While this unit was identified as a separate controller, these functions might well be collapsed into one of the other units. Nevertheless, data transmission to the user could be largely automatic with a changing priority structure for any of the data sources.

9.4 Processing Costs.

For a parametric study of this nature, processing costs should be presented as a function of throughput rate or required time per scene. Given the rapid technological development in

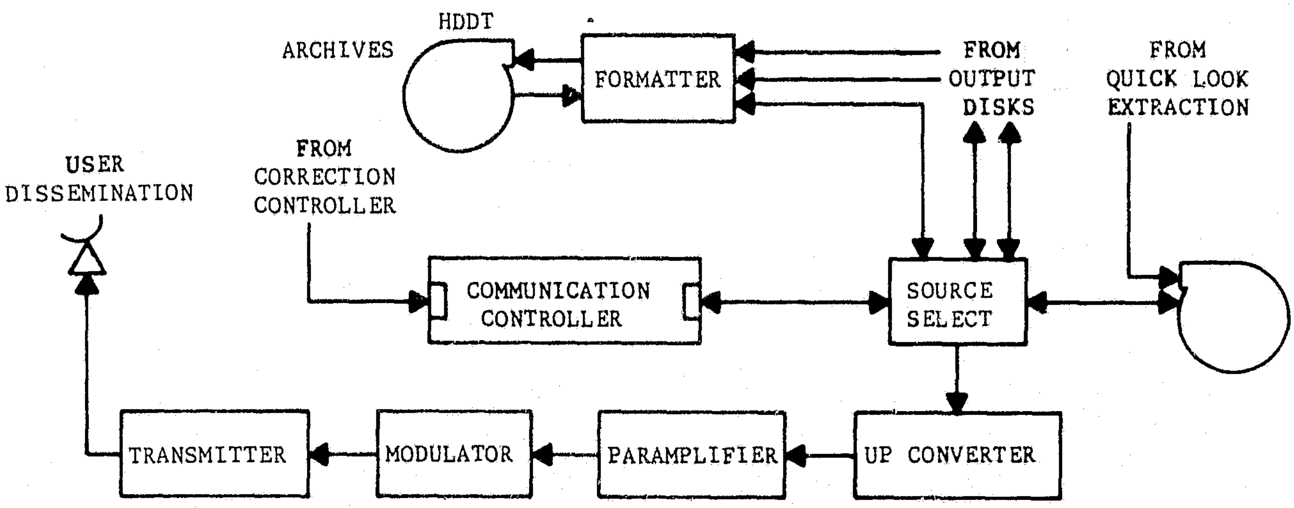


Figure 9-10. Baseline Facility Data Dissemination

processing equipment and the highly varied system design possibilities, a precise cost estimate over a wide throughput rate would involve design estimates for optional processing approaches. This was not the intent of this stud ; therefore, this approach is; 1) to estimate the cost of the baseline system described in Section 9.2, 2) to identify throughput-dependent hardware and associated costs, and 3) to vary these latter costs with processing speed. This approach will be checked subsequently in Section 11 by allowing the processing costs to vary, holding all others constant, to determine if the conclusions (e.g., regional versus central costs) change.

9.4.1 Equipment Costs: For ease of presentation, equipment costs are presented for four subsystems; 1) radio frequency reception of the ERS bulk data and the digital equipment through quick-look-data extraction, 2) correction equipment, 3) user-preprocessing equipment, and 4) trunking or user-dissemination equipment (Domsat ET's).

Table 9-5 presents the estimated cost of each hardware component needed to provide a processing time of about 10 minutes per scene for 30m/7-band data.

With minor exceptions, all equipment that is cost dependent on processing speed appears under the correction heading. Cost extrapolations, therefore, focus on this equipment. It should also be noted that the cost estimates in Table 9-5 do not include nonrecurring (software, design manuals) costs. Archival costs include one-only high-density tape recorder and controller. Some of the individual costs appearing in this table should be accurate to within 15%. Other items, however, are best estimates and are, thus, subject to uncertainty. These items are working storage, correction controller, and array processor which total $2466K or about 60% of the total estimate. The correction-controller cost was based on the use of an IBM 360-158 general-purpose machine. While the use of such a

Table 9-5

Estimated Hardware Costs

	$K	
Radio Frequency Reception (14.5-GHz Service)		
Antenna/Feed/Pedestal	$ 200	
Preamplifier (redundant)	90	
Down Converter	20	
Receiver/Demodulator	25	
Bit Sync	8	
Digital Interface	40	
Serial/Parallel/Band Conversion	20	
Instrumentation Tape Recorder (33 track @ 33 kbpi-3 required)	300	
Controller (minicomputer with small disk, teletype, 128K word storage, intermediate capacity disk)	120	
Reformatter Buffer	38	
Quick-look Extraction	30	
Quick-look Storage	35	
Quick-look Display (Scan Converter, 525 line monitor)	7	
Cables, Console and Miscellaneous	8	
Subtotal		$ 941
Correction		
Radiometric Look-up	10	
GCP Extraction	30	
GCP Buffer	3	
Microprocessor - error models	15	
Microprocessor - mapping, GCP matching	40	
Intermediate Storage - 10 disks and controller	261	
Working Storage - Input/Output	56	
Array Processor	110	
Correction Controller	2300	
Cables, Console and Miscellaneous	10	
Subtotal		2835
Post-preprocessing		
Archive tape recorder (on-line unit only)	80	
Source select logic	15	
Controller - (Minicomputer with small disk, teletype)	60	
Subtotal		155
Trunking Order Dissemination (Transmit only)		
Up Converter, modulator	10	
Power Amplifier	40	
Antenna	12	
Subtotal		62
TOTAL		$ 3993 K

computer with minicomputers and microprocessors will present interface problems, this cost based on a general-purpose computer such as the 360-158, should be an overstatement of cost, particularly in the face of current technology expansion. A more definite cost estimate would require allocation of computational functions between this machine and the microprocessors with related timeline estimates. This was not done in this study.

Correction controller costs will tend to be step functions associated with movement from one machine to the next as a bottleneck occurs. For example, an IBM 360-145 will reduce the processing speed by a factor of three [6] and the cost will be reduced by a factor of less than two (\$2300K versus \$1300K). Ignoring the processing speed discontinuity that would occur between these machines, speed versus cost was estimated by the straight-line expression;

$$C = a - bT$$

where C = Cost

T = Processing time (min/scene)

a, b = Constants

where $b = \frac{2300-1300}{29-9} = 50$

a = 3300, based on \$2800K for 10 min/scene at 30m/7-band

The above expression assumes a linear cost relationship to processing time based on current technology [7]. However, as noted in the reference, faster speeds will involve increasingly larger cost increases. Similarly, at the lower speeds, a break-point exists where minicomputer class machines in the \$100K to \$200K price range can replace the correction controller. These variations in the straight-line assumption were not investigated in this study. Rather, given total network cost, the cost elements of preprocessing equipment dependent on throughput speed were varied and their impact on total network cost was evaluated.

Using this technique, it is possible to extrapolate processing costs for regional processing requirements based on the required processing time per scene.

From the simulation (see Section 11), the required regional processing times, for CONUS coverage only, were 27.3, 41.7, and 52 minutes per scene. Again, for CONUS only, the processing time/scene requirements for a central facility was 15 minutes. With Alaska added, an Alaska regional facility required 30 minutes per scene and a central facility (CONUS and Alaska) required 10 minutes per scene. Using the described extrapolation, the respective costs for the correction processing would be:

Processing Time (Min/Scene)	Cost Estimate ($K)
10	2835
15	2550
27.3	1935
30	1800
41.7	1185
52	700

It should be noted that these estimates are for speed-dependent hardware only (30m/7-band data). Thus, total equipment costs require the addition of rf and digital, post-preprocessing trunking or user dissemination equipment costs.

The impact on equipment costs for regional-versus-central processing, CONUS data only, is thus estimated as;

	Regional (3 Centers)($K)	Central ($K)
RF & Digital	2823	941
Post-Preprocessing	465	155
Trunking	186	62
Correction	1935 (27.3 min/Scene)	2550 (15 min/Scene)
	1185 (41.7 min/Scene)	
	700 (52 min/Scene)	
TOTALS	$7294K	$3708K

The impact on equipment costs for regional-versus-central CONUS and Alaska data is thus estimated as;

	Regional (2 Centers)($K)	Central ($K)
RF & Digital	1882	1882
Post-Preprocessing	310	155
Trunking	124	185
Correction	2550 (15 min/Scene)	2835 (10 min/Scene)
	1800 (30 min/Scene)	
TOTALS	$6666K	$5057K

9.4.2 Personnel Costs: Personnel costs were estimated in the following manner. Given the base salary, X, a 15% administrative cost was added. To this number, a 40% fringe benefit cost was added. To this number, a 55% burden cost was added. Finally, a 10% profit was added. Explanations of these factors follow.

Administrative costs include supervisory and clerical salaries. Fringe benefits include costs for sick leave, vacation, insurance, and other such factors available to the individual.

Burden costs include facilities, such as buildings and power. The cost expression to support an individual at a base salary, X, is;

$$C_1 = 1.15X \qquad \text{Base plus administrative}$$

$$C_2 = (1.15X) + .4(1.15X)$$

$$= 1.51X \qquad \text{Base, administrative and fringe}$$

$$C_3 = 1.51X + .55(1.51X)$$

$$= 2.34X \qquad \text{Base, administrative, fringe, and benefits}$$

$$C_4 = 2.34X + 0.1(2.34X)$$

$$= 2.57X \qquad \text{Total individual costs}$$

Attempting to estimate personnel requirements requires an assumption of management philosophy. It is assumed here that; 1) minimum personnel are used, 2) supervisory costs are covered by the 15% allocation (for small facilities this cost would be understated), and 3) personnel costs associated with archival retrieval, filing, indexing, etc., were not estimated. Given the foregoing assumptions, it follows that the personnel cost estimates represent a minimum cost.

Personnel tasks associated with the baseline facility (Section 9.3) are divided into; operational, preprocessing and archival/dissemination. Proposed task descriptions are:

<u>Operational Engineer I</u>: Monitors data flow during acquisition and data transfer to correction processing; sets antenna for acquisition (automatic tracking) services primary tape recorder; initiates operational commands; trouble-shoots malfunctions.
Classification - Senior Engineer, base salary $9.80/hr.

<u>Data Processing Engineer</u>: Monitors data flow into and out of correction processing; interacts during GCP matching; supervises correction controller; logs processing results; trouble-shoots malfunctions.
Classification - Engineering Specialist, base salary $13.00/hr.

<u>Operational Engineer II</u>: Monitors data flow from quick-look, archives and pipeline; enters and prioritizes user requests for archival data; maintains transmission schedule; trouble-shoots malfunctions.
Classification - Senior Engineer, base salary $9.80/hr.

Clerical: Performs indexing, tape retrieval, and assorted tasks for data location; types reports, letters, etc.
Classification - Clerical, base salary $4.95/hr.

Technician: Performs local repairs; cleans and maintains tapes; annotates tapes; supplements operational engineer tasks.
Classification - Technician, base salary $5.90/hr.

Programmer: Maintains software; updates programs; capable of generating, testing, and implementing software adaptations; supplements operational engineering tasks.
Classification - Senior Programmer, base salary $9.95/hr.

In assigning these classifications to facilities, the following assumptions were made:

1. Clerical and programming personnel would be available only during one shift per day.
2. A minimum complement at any shift at any facility would be two engineers and one technician when receiving, processing, and dissemination tasks are required.
3. Each facility would operate seven days a week.
4. Every two man-years requires an additional man-year to fill in for vacations, week-ends (7 day operation), and sick leave.
5. Domsat terminals do not require personnel attendance as minor adjustments to the antenna (maximum, four times a day) can be performed by other on-site personnel.

Given these assumptions, job classifications were assigned to four types of facilities:

1. A central facility receiving, processing and disseminating data
2. A regional facility receiving, processing and disseminating data
3. A central facility receiving and processing data
4. A regional facility, receiving data (no processing)

The estimates for each of these follow.

Central Facility receiving, processing (10 to 15 minutes per scene) and disseminating data.

Day Shift - 2 operational engineers, 1 data processing engineer, 2 clerical, 2 technicians, and 1 programmer. Total base cost per hour $64.25.

Evening Shift(s) - 1 operational engineer, 1 data processing engineer, and 1 technician. Total base cost per hour $28.70.

Annual personnel costs for this facility is then estimated by extending the hourly cost over the year and accounting for 7-day operation.

The annual cost is derived by; base hourly cost times 2.57 (fringe, burden, etc.) times 40 (hours per work week) times 52 (weeks per year) times 1.5 (personnel costs for weekends, vacations, etc). Thus, for the central facility, estimated annual personnel costs are:

C-3

Day Shift	-	$509,323	(8-hour operation)
Evening Shift(s)	-	230,128	
Combined 2 Shifts	-	739,451	(16-hour operation)
Combined 3 Shifts	-	969,579	(24-hour operation)

Regional Facility receiving, processing - (30 to 50 minutes per scene), and dissemination

Day Shift - 1 operational engineer, 1 data processing engineer, 2 clerical, 1 programmer, and 1 technician. Total base cost per hour $48.55.

Evening Shift(s) - 1 operational engineer, 1 data processing engineer, and 1 technician. Total base cost per hour $28.70.

Using the same multipliers as applied to the central facility, estimated annual personnel costs are:

Day Shift	-	$389,293	(8-hour operation)
Evening Shift(s)	-	230,128	
Combined 2 Shifts	-	619,411	(16-hour operation)
Combined 3 Shifts	-	849,539	(24-hour operation)

Central Facility receiving and processing (10 to 15 minutes per scene)

Day Shift - 1 operational engineer, 1 data processing engineer, 2 clerical, 2 technicians, and 1 programmer. Total base cost per hour $54.45.

Evening Shift(s) - 1 operational engineer, 1 data processing engineer, and 1 technician. Total base cost per hour $28.70

Again, using the same multipliers, the estimated annual costs are:

Day Shift	-	$434,132	(8-hour operation)
Evening Shift(s)	-	230,128	
Combined 2 Shifts	-	664,260	(16-hour operation)
Combined 3 Shifts	-	894,388	(24-hour operation)

Regional Facility receiving or dissemination data only

Day Shift - 1 operational engineer, 1 technician, and 1 clerical. Total base cost per hour $20.65.

Evening Shift(s) - 1 operational engineer, and 1 technician. Total base cost per hour $15.70.

These convert to the following annual costs:

Day Shift	-	$165,679	(8-hour operation)
Evening Shift(s)	-	125,888	
Combined 2 Shifts	-	291,567	(16-hour operation)
Combined 3 shifts	-	417,455	(24-hour operation)

The foregoing cost estimates are certainly subject to question. They do, however, represent a minimum estimate of operational costs based on current wage levels. In order to test the impact of these estimates, in Section 11 they are varied upward relative to all other network costs.

SECTION 10.0

NETWORK SIMULATION

10.1 Introduction.

In order to support the trade-offs and evaluations of alternative earth-resources data dissemination networks, a versatile computer simulation was constructed to determine communication and data processing throughput and to evaluate the satisfaction of user timeliness constraints.

This chapter describes the simulation and illustrates the form of the simulation output with an example. Appendix H gives detailed flow charts of the entire simulation program.

The primary considerations in designing the program were to both accurately simulate the network being modeled and maintain flexibility in the program's structure to allow for quick and easy changes to create alternative network designs.

Parameters that can be changed with little difficulty are: number of earth-resources satellites, their period and data rate; number of receiving earth terminals; preprocessing locations (e.g., centralized in one location vs all or part of preprocessing at each region); computer storage and speed; and number of hours that each part of the network is operational. Data for nominal and expanded user demand models has also been generated and can be interchanged easily for satellite scanners with either 30-meter resolution/7 spectral bands or with 10-meter resolution/12 spectral bands.

Key features of the simulation are shown in Table 10-1. This simulation was written as a discrete-event simulation using the GESIM language (GESIM is virtually equivalent to GPSS-III). This language was chosen to gain maximum flexibility in supporting trade-off studies of several data dissemination concepts.

10.2 Simulation Inputs/Variables/Outputs

In general, the computer simulation inputs, variables, and outputs are:

- Inputs
  Functional Distributions
  Network Types
- Variables
  Number of Users
  Computation Speed
  Primary Data Rates

- <u>Outputs</u>

  Memory Size Requirements

  Data Processing Load Requirements

  Queue Lengths

  Waiting Times

  Percentage of Users Satisfied (by time of product delivery)

Table 10-1

Simulation Key Features

KEY FEATURES

- SIMULATE SWATHS OVER CONTINENTAL U.S. (41 FOR ERTS ORBIT, 64 FOR LANDSAT D ORBIT)
  - USERS PER SWATH IDENTIFIED
  - USER TIMELINESS SPECIFIED
  - USER DATA VOLUME SPECIFIED
- COMMUNICATION DATA RATES CALCULATED BETWEEN SATELLITES, CENTRAL FACILITY, AND REGIONAL FACILITIES
- PREPROCESS ALGORITHM COMPUTATIONAL REQUIREMENTS CALCULATED
  - REFORMATTING
  - RADIOMETRIC CORRECTION
  - GEOMETRIC CORRECTION
  - ARCHIVING
  - STORAGE AND ROUTING
- EVENT ORIENTED SIMULATION - GESIM LANGUAGE

More specific input and output parameters are listed in Table 10-2 and Table 10-3, respectively. However, since the simulation was constructed to support configuration trade-offs, the format and content of these parameters can be changed extensively from run to run. Figure 10-1 illustrates the type of information from the user demand model included in the simulation.

10.3 Simulation Structure.

Initially, the simulation was structured around the centralized concept; however, provision was made in the simulation for modifications and, during the study, alternatives were incorporated. Figure 10-2 summarizes the possible choices currently built into the simulation.

The basic sequence of events from user demand for data-to-user reception of data that was incorporated into the simulation is shown in Figure 10-3. During the phased development of the simulation, provisions for all of these events were included. Initially, however, modeling efforts were concentrated on the sequence from the time the swath data is actually received at a ground station until the data is delivered to the communication concentration node.

Table 10-2

Simulation Input Parameters

SWATH DESCRIPTORS
- SWATH NUMBER
- SATELLITE LOOK TIME WINDOW (START AND FINISH TIMES)
- SWATH LENGTH

SATELLITE DESCRIPTORS
- IFOV
- NUMBER OF BANDS
- DATA TRANSMISSION RATE
- NUMBER OF SATELLITES

COMPUTER/ALGORITHM DESCRIPTORS
- COMPUTER ARCHITECTURE AND COMPUTATIONAL THROUGHPUT (MIPS)
- ALGORITHM FUNCTIONAL MODEL AND INSTRUCTION COUNT

USER DESCRIPTORS
- SWATH NUMBER
- FRACTION OF SWATH DATA REQUIRED
- TIMELINESS REQUIRED
- FACILITY THAT STORES DATA FOR USER DISSEMINATION

DATA DISTRIBUTION DESCRIPTORS
- NUMBER OF REGIONAL CENTERS
- REGIONAL (OR CENTRAL) CENTER ASSOCIATED WITH EACH SWATH

Table 10-3

Simulation Output Parameters

Buffer and Processor Memory Size Requirements
- Maximum Contents
- Average Contents
- Average Utilization
- Average Resident Time
- Current Contents (at snapshop)

Data Processor Load Requirements
- Average Utilization
- Average Processing Time
- Throughput

Trunking Load Requirements
- Average Utilization
- Average Transmission Time
- Throughput

User Requirement Satisfaction
- Distribution of Data Product Age at Delivery for Various User Classes

USER IDENTIFICATION	USER LOCATION	NO. OF BANDS	LENGTH (N.M.)	TIMELINESS (DAYS)	PROBABILITY OF DEMAND
156 USACE	CHARLESTON	6	180	5	0.29
157 USACE	CHARLESTON	6	180	1	0.29
158 USACE	CHARLESTON	6	25	1	0.145

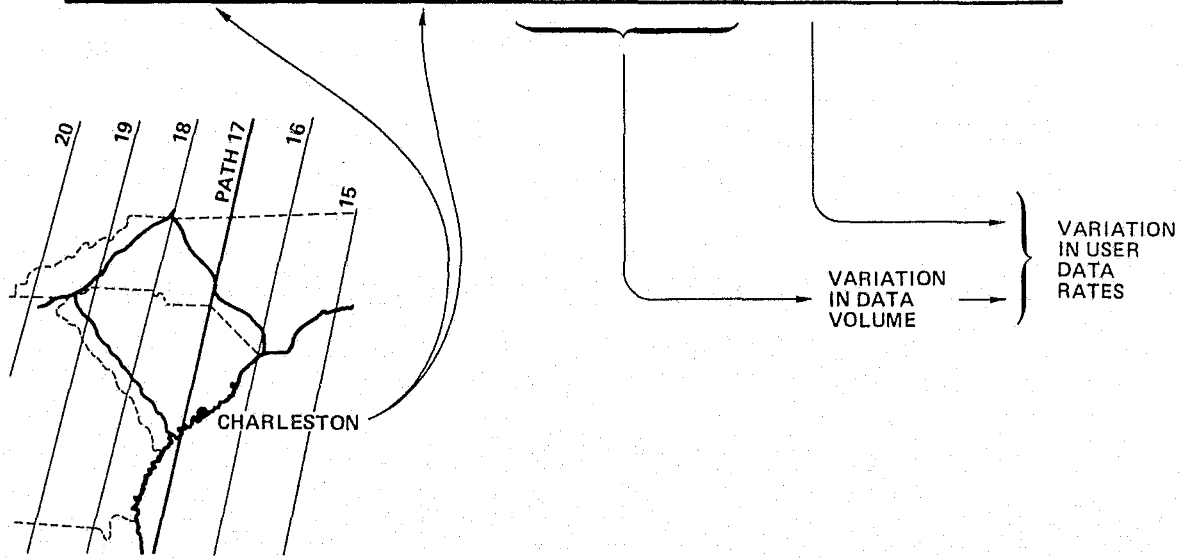
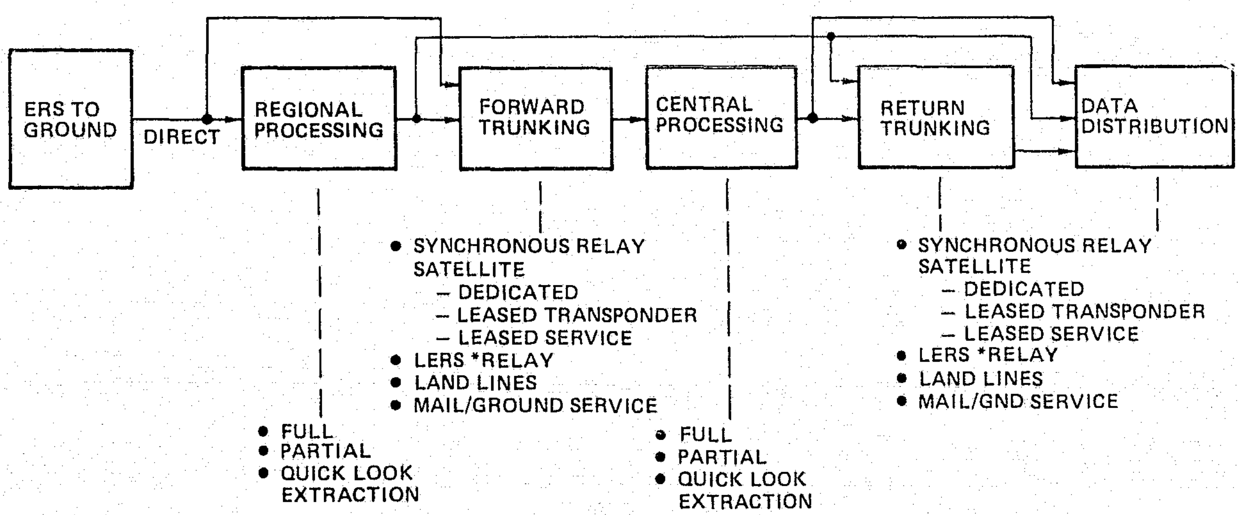


Figure 10-1. User Demand Model - Example Corps of Engineers



*LOW EARTH-RESOURCES SATELLITE

Figure 10-2. Network Simulation Configuration Definition

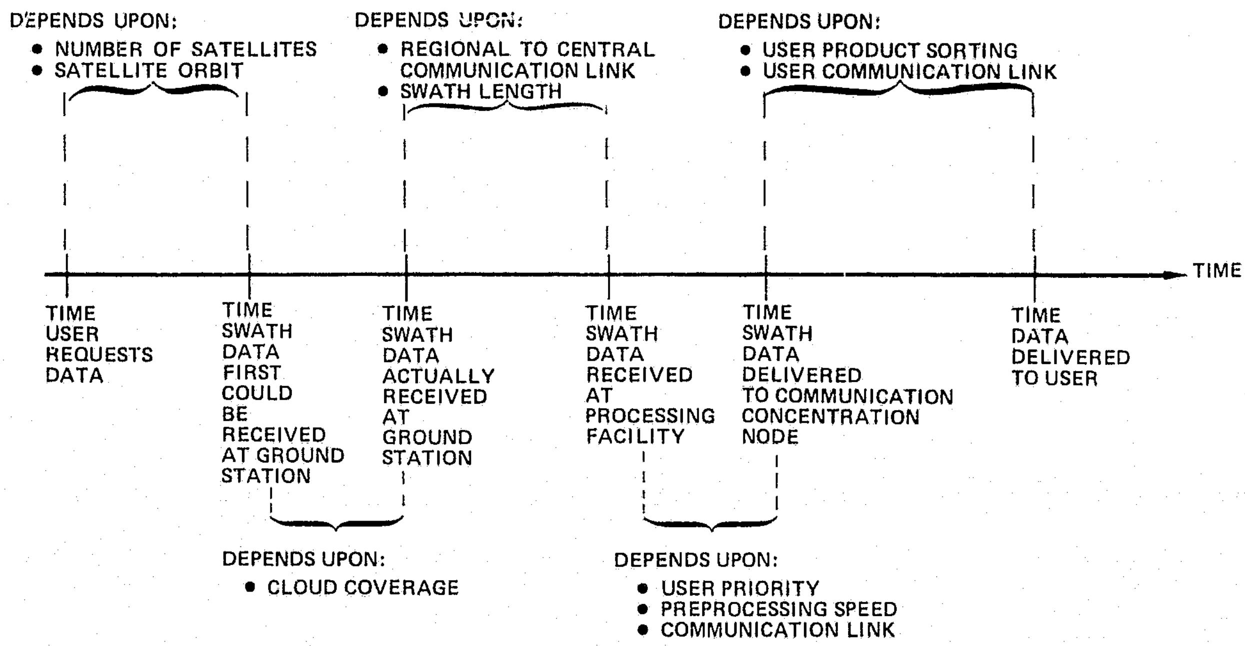


Figure 10-3. Basic Sequence of Stochastic Events Incorporated into the Simulation

The functional structure of the simulation is illustrated in Figure 10-4, which shows the basic information flow paths. It should be emphasized that, since the simulation is a discrete-event simulation, multiple, simultaneous events may (and usually do) occur in each of the various functional blocks shown.

The Earth Resources Data Dissemination Simulation program has several versions, each corresponding to a basic network structure (e.g., central preprocessing versus regional preprocessing). This program consists of eight segments: (1) the data base (functions and variables), which defines most of the capabilities of the entire system (e.g., satellite-station contact times and durations, processor speeds, data rates, throughput of data lines, etc.) as well as the user demand model (number of possible users of a swath, individual user-request probabilities, and percent of swath requested and data timeliness* specified by each user; (2) the run-timer segment which defines how long the simulation is to run; (3) the shift-timer segment which determines when the various facilities are operating; (4) the satellites with orbit 103 (98) minutes and cycle 252 (264) orbits for the ERTS (LANDSAT) satellite; (5) the regional stations which may either act only as buffers and data relays from the satellites and the central facility or perform preprocessing and dissemination to user tasks; (6) the communication links which deliver data from the regional stations to the central facility (if one exists) and from the processing centers to the users; (7) the central facility (modeled, of course, only in the centralized configuration) which receives data

*Maximum acceptable age of data.

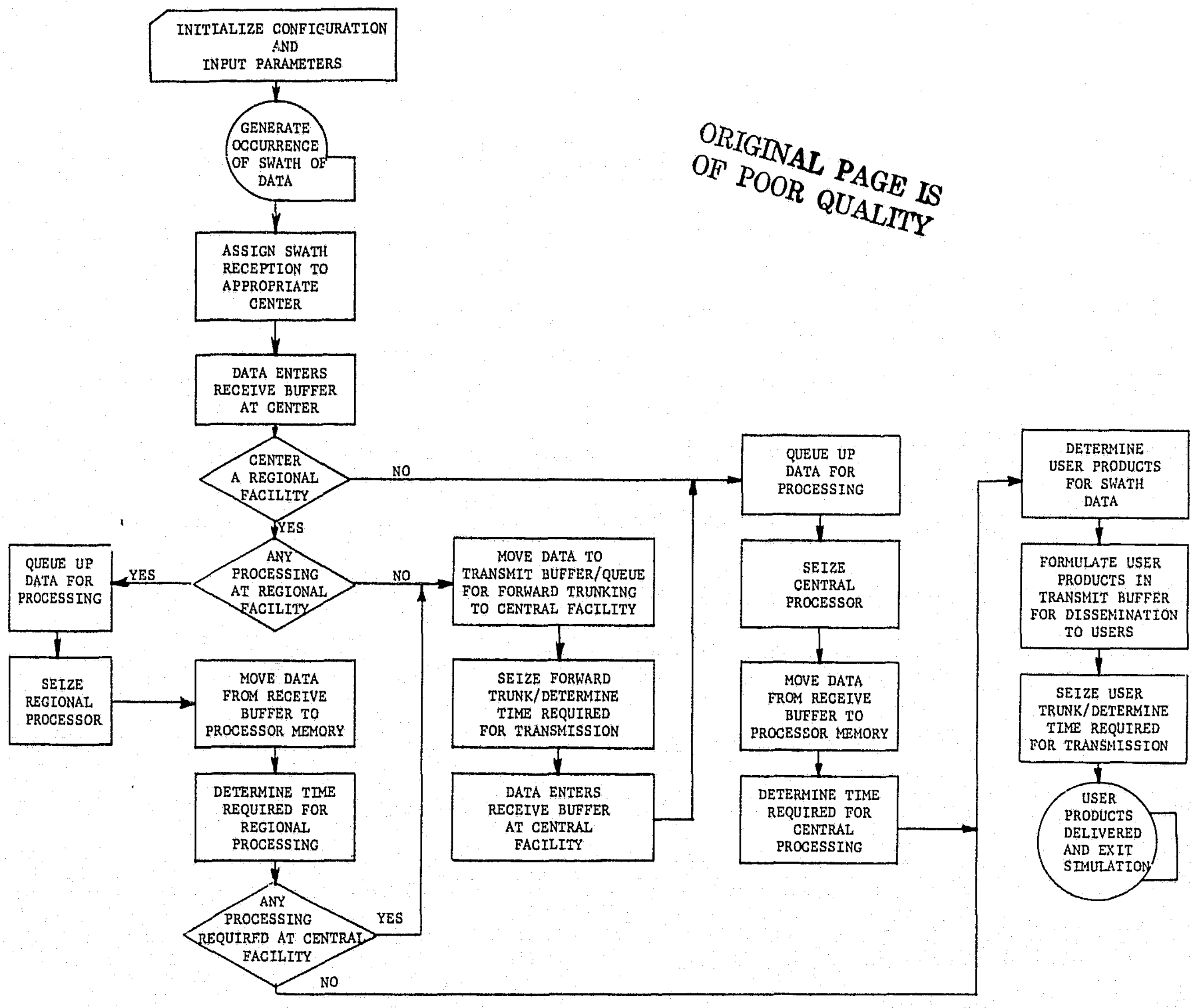


Figure 10-4. Simulation Functional Structure

directly from the satellites and from all of the regional stations, performs all remaining preprocessing tasks and routes the data to users; (8) the users when the data's journey ends and statistics are gathered.

10.3.1 The Data Base: The data base consists of 214 functions and usually 20-25 variables (more are added for some versions of the program).

Functions 1-212 are functions associated with user demands. There are 70 swaths of data that are received by the ground station and there are three list functions associated with each. The swaths are numbered 1-70; for swath $n(1 \leq n \leq 70)$, function 3n-2 lists the percentage of the swath demanded by each user, function 3n-1 lists the demanded timeliness

(maximum acceptable age) of the data by each user, and function 3n lists the probability that each user asks for the data at each occurrence of its availability.

Function 211 is a test function providing the number of possible users of each swath. Function 212 is a discrete function that establishes the priority of each user request based on the timeliness demanded.*

Functions 213 and 214 establish the interaction of the satellites and the receiving terminals. Function 213 indicates what station receives data from each swath. Let f(s) be the value of Function 213. Then

$$f(s) = \begin{cases} 0 \text{ if the orbit, s, contains no data of interest} \\ n > 0 \text{ if the data from orbit s is received by station n} \end{cases}$$

f(s) is defined sequentially; i.e., argument s indicates the s^{th} orbit of the satellite since its cycle of 252 orbits began.

Function 214 defines the duration of contact of the satellite with the station receiving its data. This information is then used to compute the data volume contained in the swath.

The variables are defined in Table 10-4 (V_1 indicates variable i). Variables other than those tabulated may be used to change network configurations during multiple runs or for other purposes.

10.3.2 <u>The Run Timer</u>: A Generate Block sends a timer pulse every 24 hours and the model may be run for any number of days. The basic unit of time used in the program is the second and each duration is in whole seconds (i.e., there are no fractional delays).

10.3.3 <u>The Shift Timer</u>: After an initial interval of 16 hours when the facilities are available (day and swing shift), a Generate Block sends a timer pulse which preempts all of the facilities modeled so that they are unavailable. They remain preempted for 8 hours and are, then, again made available. Twenty-four hours after the first pulse and every 24 hours thereafter for the duration of the run, the process of preemption (8-hour interval - release) is repeated, thus modeling a two-shift work day. In using the preemption technique,

*Let t_n be the age of the swath of data after reformatting, radiometric correction, geometric correction and other preprocessing done to the entire swath (e.g., cloud filtering). Let X be the time that it will take to transmit the user's request via the communication channel being used (simply, the data volume divided by the transmission rate, and let T be the timeliness demanded by the user). Then, the quantity $E_t = T - t_n - X$ indicates the amount of "excess time" remaining to meet the demand. The requests are assigned 8 levels of priority (0-7) with higher priority given to those with smaller values of E_t (how the priorities are assigned is, to some extent, arbitrary but also flexible).

the facilities are used optimally since they are available for precisely 16 hours. Other modeling techniques considered would have made the facilities artificially available either too much or too little, but it is believed that in a real world situation, planning would be implemented that would approach the perfect facility availability of the model.

Table 10-4

Simulation Variable Definitions

V_1 - V_4:	Define the orbit and swath of the "second" satellite which is one half the orbit cycle ahead of the other satellite.
V_5:	Specifies the data volume of the swath (defined by the resolution and number of spectral bands of the satellite scanner).
V_6:	The time required to route and store each user request.
V_7 - V_9:	Pointers to facilities. In general, for i = 7, 8, 9, if $V_i \equiv k \mod (n)$ (where n is the number of regions being modeled) then V_i points to a facility at region station k.
V_{10}:	The amount of data remaining after cloud filtering.
V_{11}:	The time required for the cloud filtering algorithm.
V_{12}:	Transmission time from a region to the central facility.
V_{13}:	The time required for the primary preprocessing tasks - radiometric and geometric correction, etc.
V_{14}:	The difference between the timeliness requested and the sum of the age of the data when the user's data is about to be stored and routed and the expected transmit time once transmission is begun - used to assign priority.
V_{15}:	Three times the swath number (where the swath number indicates the number of station contacts of the satellite since its cycle began with orbit 1) - used to point to the 3 correct user demand functions.
V_{16}:	The difference of the timeliness requested and the age of the received data.
V_{17}:	$- V_{16}$
V_{18}:	Number of possible users of swath - 1. (Index to the random number generator).
V_{19}:	Data volume requested by a user.
V_{20}:	Time to transmit data to a user.
V_{21}:	The MIPS (mega instructions per second) of the preprocessing computer.
V_{22} - V_{23}:	Transponder rates.
V_{24}:	Pointer to SAVE VALUES 3 & 4 - used when orbit cycles are re-initialized.

10.3.4 The Satellites: Each satellite is simulated with a Generate Block which has as its A-field argument, n, the orbit period of the satellite, in seconds. Every n seconds of simulated time, the Generate Block sends a transaction into the model; if function 129 is non-zero for the transaction, it represents a swath of data of interest; otherwise, it is immediately terminated. C-field offsets are used so that no two satellites are transmitting to a station simultaneously - in the case of two satellites, one satellite has offset [n/2],* the other 0.

10.3.5 The Regional Stations: The principal components of the "regional stations" segment are the storages and the computer facility. One storage represents the sum total of the memory required at the region, two others represent the buffer that receives data from the satellite and the transmit buffer that holds data waiting to be transmitted. Finally, there is a storage to represent processor memory. The storage representing the memory does not attempt to model the actual transfer of data in and out of memory as it would actually be performed; the whole swath of data is brought into storage at once, where in reality that probably never occurs. However, it is in the computer that the volume of data in a swath would either increase or decrease and the "processor memory" storage helps to explain that change.

The "computer" facility is seized and is held for a period determined by the data volume being processed, the instruction count of the algorithms used, and the speed of the computer. Section 10.4 describes the functional instruction count models of the algorithms developed.

10.3.6 The Communication Links: The communication links are, in some cases, modeled as facilities, in others, as storage. Facilities are used when transponders on the satellite are modeled since (1) they are used for communications requiring high data rates (e.g., 40 Mbps) so that relatively few are required to handle the data volume, and (2) by using facilities, the utilization of each transponder can be determined. Storages do not provide information on the utilization of each link but do allow for the simple modeling of the many links necessitated by the slower data rates of ground lines.

10.3.7 The Central Facility: The central facility is modeled in much the same way as the regional facilities with an additional storage buffer which receives data from other regions.

In a centralized configuration, if the data requested by each user is to be transmitted separately (i.e., a broadcast mode of dissemination is not used, a separate data package is created at the central facility to satisfy each request (overlapping of user-request land areas, notwithstanding).

*[n/2], the greatest integer less than or equal to n/2.

10.3.8 The Users: Tabulations are made on statistics such as the age of the data and the distribution of time-constraint satisfaction (i.e., how early or late is the data). In addition, in the broadcast mode, the user model assumes that there is at least one requestor for every swath of data.

Appendix H contains the flow chart of the simulation of the centralized configuration with no broadcast mode. All segments crucial to the logical flow of the program are shown except the "Run-Timer Segment" which would vary with the number of days that one wishes to simulate, the frequency that one wishes to see statistical surveys (e.g., every day, or once a week), etc. Other versions of the program are easily created with small modifications to the one of Appendix H, since they are basically simplifications of that version.

10.4 Algorithm Instruction Counts.

In order to determine the data processing time required to perform the preprocessing algorithms, the algorithms must be explicitly defined and the computer instructions required to execute the algorithm must be enumerated. Five preprocessing algorithms have been considered. Figure 10-5 identifies these algorithms and presents their sequence of execution. The "demand" algorithm represents users who wish to utilize data stored in the archives. These users are in addition to the day-to-day or week-to-week regular users. Brief descriptions of the purpose of the other algorithms are given below:

- Reformatting

  Data received from satellite packed by band number, line number, then pixel number. The algorithm repacks data by pixel number, band numbers, then line number.
- Radiometric Correction

  Calibration data is used to determine a correction bias and gain that is used to upgrade the data.
- Geometric Correction

  Pixel by pixel, position inaccuracies in data, due to platform error, are corrected with fifth-order polynomials
- Archival Storage

  Corrected data is stored for future use in specified format
- Storage and Routing

  Data is sorted into blocks for routing to users

Functional instruction count models for each of the above algorithms have been constructed using the algorithms taken from "A Study of Ground Data Handling Systems for Earth Resources Satellites," Vol. III, Philco-Ford Houston Operation. Basic instructions counted were add, subtract, multiply, divide, store, and recall. Table 10-5 lists the resulting instruction count model equations. These equations assume a serial computer and a swath width of 100 nautical miles (1.852×10^5m). The first equation therein estimates the data processing

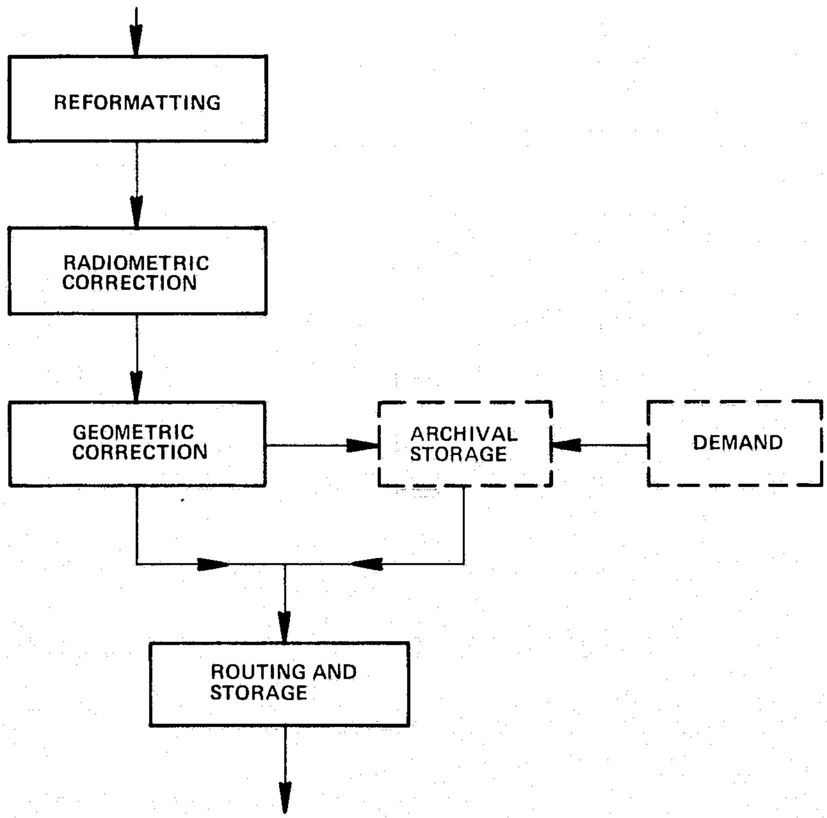


Figure 10-5. Data Preprocessing Algorithm

time required to perform the reformatting algorithm for swath length, S_W, as a function of the satellite parameters and the computer instruction execution times. Equation 2 estimates the data processing time required to perform the radiometric correction algorithm. Equation 3 estimates the data processing time required to perform a geometric correction algorithm which incorporates a Kalman filter and a fifth-order polynomial fit. Equation 4 estimates the data processing time required to store the data from swath length, S_W, into the archives. For a set of 1 users, Equation 5 estimates the data processing time required to repack the archived data into data blocks for each user. The total time is merely the sum of the time required for each user.

10.5 Simulation Example.

In order to illustrate the use of the simulation and the form of the output, an example earth resources data dissemination configuration is presented in this section. The simulation example assumptions are as follows:

- 2 Earth Resources Satellites - 30m IFOV, 7 bands
- ERTS Orbits - period of 18 days

Table 10-5

Data Processing Requirements for Swath Length, S_W

1. REFORMATTING

$$T_{RF} = \frac{S_W}{R \times N}\left[\left(2 + S_B \times N\left(\frac{1.852 \times 10^5}{R} + 18\right)\right) T_A + S_B \times N\left(\frac{1.852 \times 10^5}{R}\right) T_S + S_B \times N\left(\frac{1.852 \times 10^5}{R} + 18\right) T_{ST} + S_B \times N\left(\frac{1.852 \times 10^5}{R} + 18\right) T_{RC}\right]$$

WHERE	T_A	= ADD TIME	S_B	=	NUMBER OF BANDS
	T_S	= SUBTRACT TIME	R	=	IFOV (M)
	T_{ST}	= STORAGE TIME	N	=	NUMBER OF SENSORS
	T_{RC}	= RECALL TIME	S_W	=	SWATH LENGTH

2. RADIOMETRIC CORRECTION

$$T_{RAD} = \frac{S_W \times S_B}{R}\left[\left(14 + \frac{1.852 \times 10^5}{R}\right) T_A + 4T_S + \left(2 + \frac{1.852 \times 10^5}{R}\right) T_M + 3T_D\right]$$

WHERE T_M = MULTIPLY TIME

T_D = DIVIDE TIME

3. GEOMETRIC CORRECTION

$$T_{GEO} = \frac{S_W}{R}\left[72 \times \frac{1.852 \times 10^5}{R} T_A + 116 \times \frac{1.852 \times 10^5}{R} T_M\right]$$

4. ARCHIVAL STORAGE

$$T_{ARC} = \frac{S_W}{R \times M}\left[14 + M \times S_B \times \left(9 + \frac{1.852 \times 10^5}{R}\right)\right] T_{ST}$$

WHERE M = NUMBER OF LINES IN A SCENE

5. STORAGE AND ROUTING

DEFINE THE USER SET I = 1, 2, . . ., I

$$T_{SR} = \sum_{I=1}^{I} \frac{S_{WI}}{R \times M}\left[14 + M \times S_B \times \left(9 + \frac{1.852 \times 10^5}{R}\right)\right] (T_{ST} + T_{RC})$$

WHERE S_{WI} = THE SWATH LENGTH OF USE TO USER I

- 102-Mbps down-link to one of two receiving stations
- 2 Centers - Sioux Falls, SD - Central
  Fairbanks, AK - Regional
- Regional facility linked to central via 6.5-Mbps channel
- All preprocessing performed at central
  - Reformatting
  - Radiometric correction
  - Geometric correction
  - Archive storage/retrieval
  - Storage and routing

- 20 MIPS serial processor
- Expanded user demand model
- Data broadcast to all users via 6.5-Mbps channel - shared with forward trunking from regional facility to central.
- Queueing discipline for 6.5 Mbps was first-come-first-serve with forward trunking given higher priority.
- 35 days simulated with 16-hours/day operation

Figure 10-6 pictorally illustrates the simulation example configuration. Various queues, storages, and facilities (computer or communication link) are shown with their identification numbers. These identification numbers correspond to those on the standard output summaries shown in Figure 10-7.

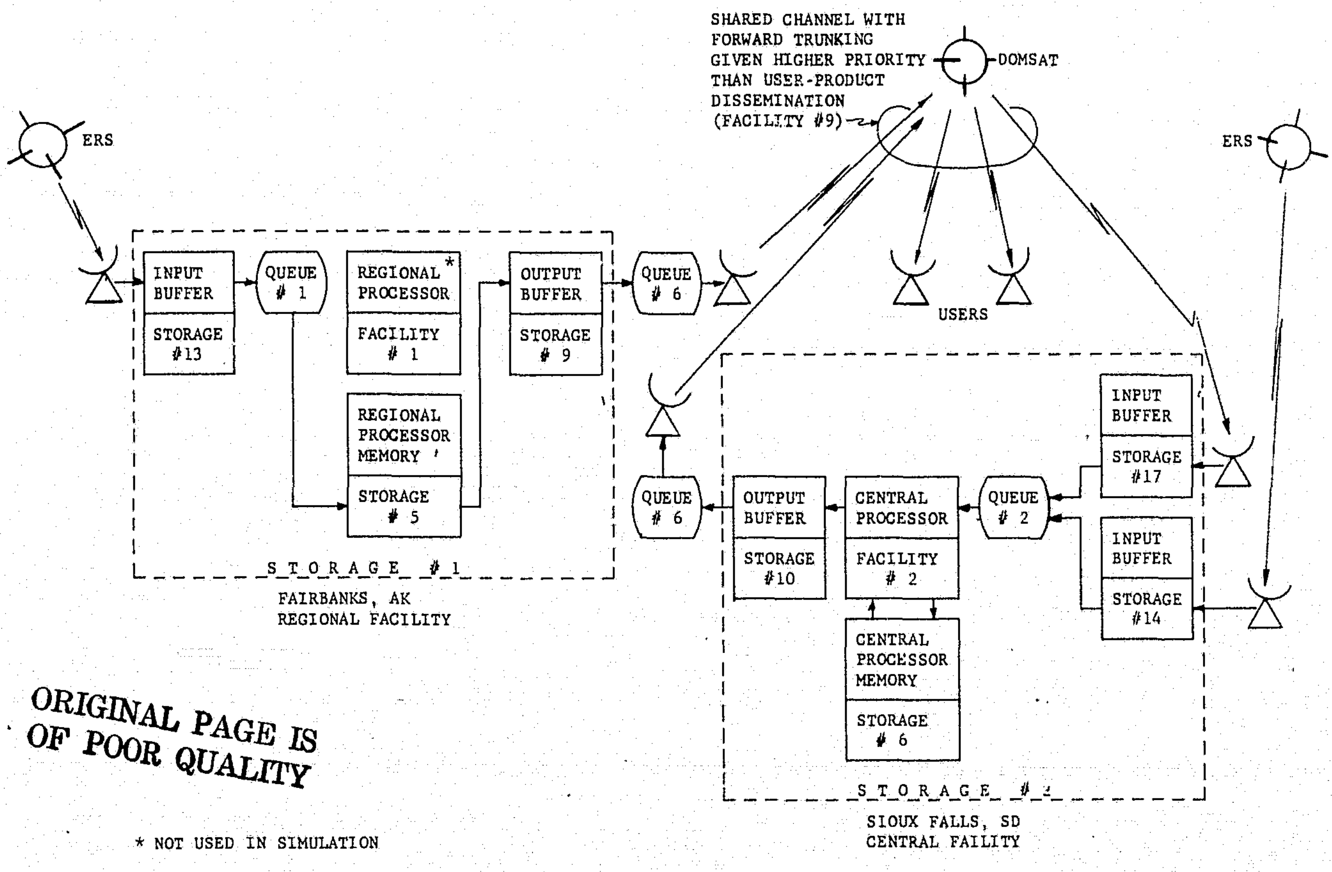


Figure 10-6. Simulation Example Configuration

The standard output summaries give various accumulated statistics gathered during the simulation run. Note in Figure 10-7 that the central processor (Facility #2) processed 295 swaths of data in 35 days with an average processing time of 1.87 hours (6733.75 seconds) and was 60.57% utilized (.6057 = 1.5 (.7371-.3333)) during its hours of operation (16 hours/day). Other similar statistics can be extracted from the printout for other system elements.

SUBTRACT 0.333 AND MULTIPLY BY 1.5 TO GET UTILIZATION FOR 16-HOUR OPERATION

SUBTRACT 36 TO GET SWATH COUNT

TIME IN SECONDS

F A C I L I T Y

FACILITY REFERENCE	AVERAGE UTILITY	# OF ENTRIES	AVERAGE TIME/TRANS	SEIZING TRANS #	PREEMPT TRANS #	
1#	.3333	168	6000.00	0	6	
2#	.7371	331	6733.75	0	6	FACILITY #2 IS CENTRAL PROCESSOR
3#	.3333	36	28000.00	0	6	
4#	.3333	36	28000.00	0	6	
5#	.3333	36	28000.00	0	6	
6#	.3333	36	28000.00	0	6	
7#	.3333	36	28000.00	0	6	
8#	.3333	36	28000.00	0	6	
9#	.8428	463	5504.37	0	6	FACILITY #9 IS DOMSAT SHARED CHANNEL
10#	.3333	36	28000.00	0	6	
11#	.3333	36	28000.00	0	6	
12#	.3333	36	28000.00	0	6	
13#	.3333	36	28000.00	0	6	
14#	.3333	36	28000.00	0	6	
15#	.3333	36	28000.00	0	6	
16#	.3333	36	28000.00	0	6	

STORAGE CAPACITY SET TO ∞

OF 10^8 BITS

TOTAL # OF 10^8 BITS OVER ENTIRE SIMULATES TIME

OF 10^8 BITS

S T O R A G E

REFERENCE	CAPACITY	AVERAGE CONTENTS	AVERAGE UTILITY	ENTRIES	AVERAGE TIME/TRANS	CURRENT CONTENTS	MAXIMUM CONTENTS	
1#	131071	55.98	.0004	24621	6875.45	0	722	TOTAL REGION-1 MEMORY - ALASKA
2#	131071	462.37	.0035	75526	18512.86	0	1440	TOTAL REGION-2 MEMORY - SIOUX FALLS
5#	131071	.00	.0000	24621	.00	0	332	REGION-1 PREPROCESSOR MEMORY
6#	131071	123.98	.0010	75526	4964.20	0	443	REGION-2 PREPROCESSOR MEMORY
9#	131071	185.48	.0014	49242	11390.66	0	762	REGION-1 TRANSMIT BUFFER
10#	131071	145.99	.0011	50905	8672.58	0	793	REGION-2 TRANSMIT BUFFER
13#	131071	.00	.0000	24621	.00	0	332	REGION-1 RECEIVE BUFFER
14#	131071	57.16	.0004	50905	3395.48	0	746	REGION-2 RECEIVE BUFFER
17#	131071	5.73	.0000	24621	704.02	0	332	INTER-REGIONAL BUFFER

Q U E U E

QUEUE REFERENCE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	TOTAL AVE. TIME/TRANS	NZERO AVE. TIME/TRANS	QTABLE NUMBER	CURRENT CONTENTS	QUEUE FOR
1#	1		132	132	100.0			5	0	REGION-1 PROCESSOR
2#	2	.22	295	91	30.9	2616.07	3783.04	6	0	REGION-2 PROCESSOR
6#	5	.73	427	83	19.4	5941.03	7374.48	9	0	DOMSAT SHARED CHANNEL

Figure 10-7 Simulation Example Output

Another type of output available from the simulation is in the form of distributions. Figure 10-8 shows three such distribution printouts for the simulation example. Printouts of this form are extremely valuable in determining system design biases that may not be observable from mean-value estimates, alone. For example, the printout of Table #10 (from Figure 10-8) shows that, even if the data products destined for users requiring one-day delivery from observation is delayed by 6 hours (21600 seconds), the timeliness deadline for all such users will still be met. In the following section (Section 11), the results of a number of simulation runs for the various configurations are analyzed.

T A B L E STATISTICS FOR # 1 DISTRIBUTION OF AGE (SECONDS) OF DATA PRODUCTS AT USER DELIVERY TIME

ENTRIES	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	NON-WEIGHTED
6418	20620.391	9452.045	33085417.500	

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	*** CUMULATIVE *** PERCENTAGE	REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	0	.00	.0	100.0	.000	-2.182
10800	866	13.49	13.5	86.5	.524	-1.039
21600	2512	39.14	52.6	47.4	1.048	.104
32400	2819	43.92	96.6	3.4	1.571	1.246
43200	0	.00	96.6	3.4	2.095	2.389
54000	92	1.43	98.0	2.0	2.619	3.532
64800	129	2.01	100.0	.0	3.143	4.674

THE REMAINING FREQUENCIES ARE ALL ZERO

T A B L E STATISTICS FOR # 9 DISTRIBUTION OF WAITING TIME (SECONDS) FOR DOMSAT SHARED CHANNEL

ENTRIES	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	NON-WEIGHTED
427	5941.033	6046.746	2536821.000	

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	*** CUMULATIVE *** PERCENTAGE	REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	83	19.44	19.4	80.6	.000	-.982
10800	245	57.38	76.8	23.2	1.818	.804
21600	95	22.25	99.1	.9	3.636	2.590
32400	0	.00	99.1	.9	5.454	4.376
43200	4	.94	100.0	.0	7.272	6.162

THE REMAINING FREQUENCIES ARE ALL ZERO

T A B L E STATISTICS FOR # 10 DISTRIBUTION OF TIMELINESS (SECONDS) FOR USERS REQUIRING 1-DAY DELIVERY

ENTRIES	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS	NON-WEIGHTED
1928	67252.337	8950.601	32415626.250	

UPPER LIMIT	OBSERVED FREQUENCY	PER CENT OF TOTAL	*** CUMULATIVE *** PERCENTAGE	REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
-43200	0	.00	.0	100.0	.642	-12.340
-32400	0	.00	.0	100.0	.482	-11.134
-21600	0	.00	.0	100.0	.321	-9.927
-10800	0	.00	.0	100.0	.161	-8.720
0	0	.00	.0	100.0	.000	-7.514
10800	0	.00	.0	100.0	.161	-6.307
21600	0	.00	.0	100.0	.321	-5.100
32400	25	1.30	1.3	98.7	.482	-3.894
43200	19	.99	2.3	97.7	.642	-2.687
54000	0	.00	2.3	97.7	.803	-1.481
64800	713	36.98	39.3	60.7	.964	-.274
75600	846	43.88	83.1	16.9	1.124	.933
86400	325	16.86	100.0	.0	1.285	2.139

THE REMAINING FREQUENCIES ARE ALL ZERO

Figure 10-8. Simulation Example Distribution Outputs

SECTION 11.0

NETWORK CONFIGURATION COMPARISON AND SELECTION

11.1 Introduction.

In Section 9, the various electronic transmission alternatives were compared. It was shown that, given the user model of Section 5, a version of the UOT satellite system is the least-cost transmission alternative for data dissemination by electronic transmission. Moreover, this result is independent of the particular class of network topology that may be used. In this section, therefore, a satellite data dissemination system is assumed and various realizations of the three candidate network topologies (Figure 8-1) are compared by computer simulation using the simulation program described in Section 10. (Each realization is hereinafter referred to as a network configuration or, more simply, as a network.) Based on the results of these simulations, the costs of the various configurations are developed and compared for a 30-meter-resolution/7-spectral-band ERS data source. The results are given both as total system and as approximate per-user equivalent annual costs. Finally, the sensitivity of the cost comparisons to changes in the estimated cost of preprocessing equipment and of operating personnel, and to changes in the raw data rate corresponding to a 10m/12-band ERS sensor is determined.

11.2 Network Configurations.

Figures 11-1 through 11-3 show the network configurations evaluated in this study. Configurations 1 and 2 compare regional versus central preprocessing facilities for coverage of the lower-48 states. (Three regional ERS readout terminals in the lower-48 states are necessary for lower-48-state coverage when the ERS-to-readout-terminal link frequency is at 40 GHz or above. See Section 7.1.1.4 and Figure 7-3.) Configuration 3 centralizes the raw data reception function to one readout station located at Sioux Falls. This is possible provided the minimum elevation angle to the ERS is allowed to drop to 5° (see Figure 7-2).

Alaska was not included in the first three configurations for three reasons: 1) It is of interest to determine the effect on a data dissemination network of adding the demand for Alaska data, 2) the demand models for the lower-48 states were completed before those for Alaska and could thus be used (while the Alaska models were being completed) to gain understanding of the simulation program and the interpretation of simulation results, and 3) results from these simulations (regarding the performance of various network topologies) would help determine simulation sequences for the longer, more complex, combined Alaska-and-lower-48-state runs.

Configurations 4 and 5 (Figure 11-2) include Alaska in addition to the lower-48 states. Configuration 4 is configuration 3 with a separate ERS readout terminal and preprocessor for Alaska. Configuration 5 centralizes all preprocessing at Sioux Falls.

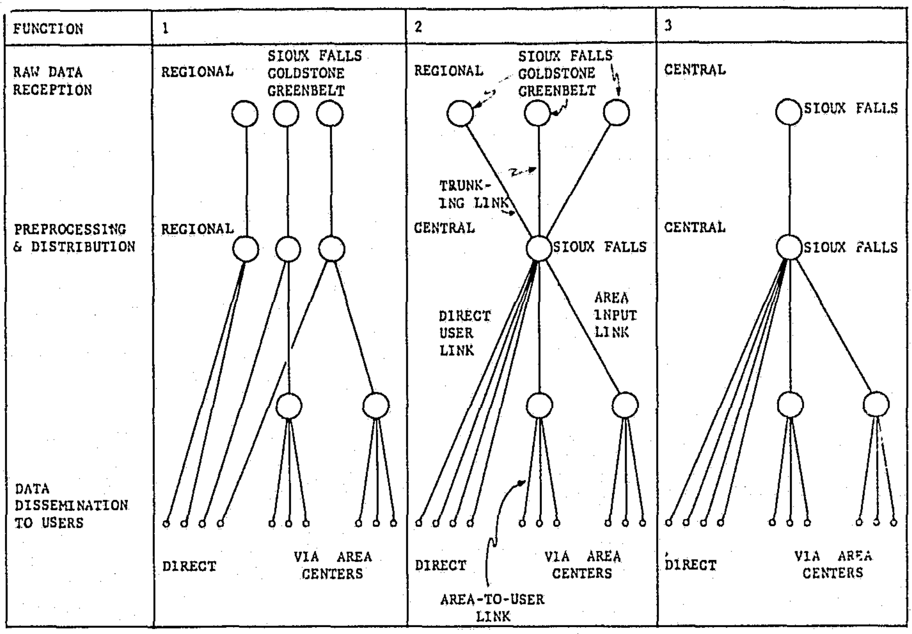


Figure 11-1. Network Configurations - Lower 48 States

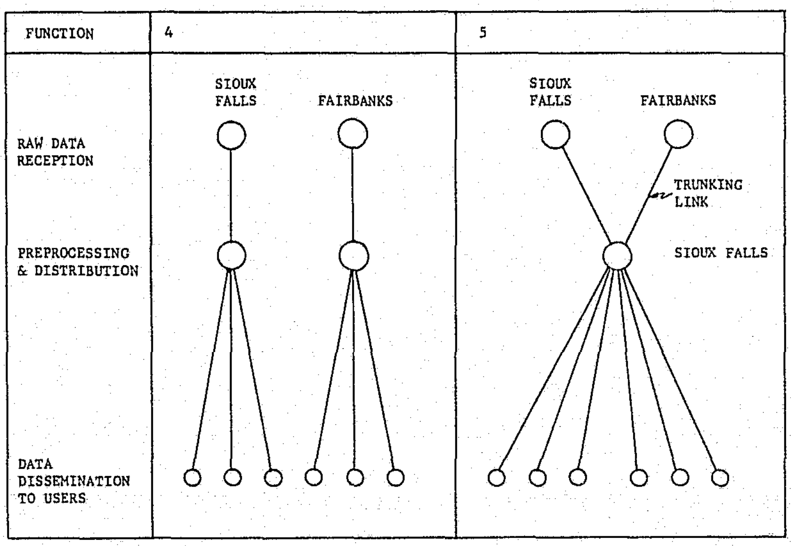


Figure 11-2. Network Configurations - Including Alaska

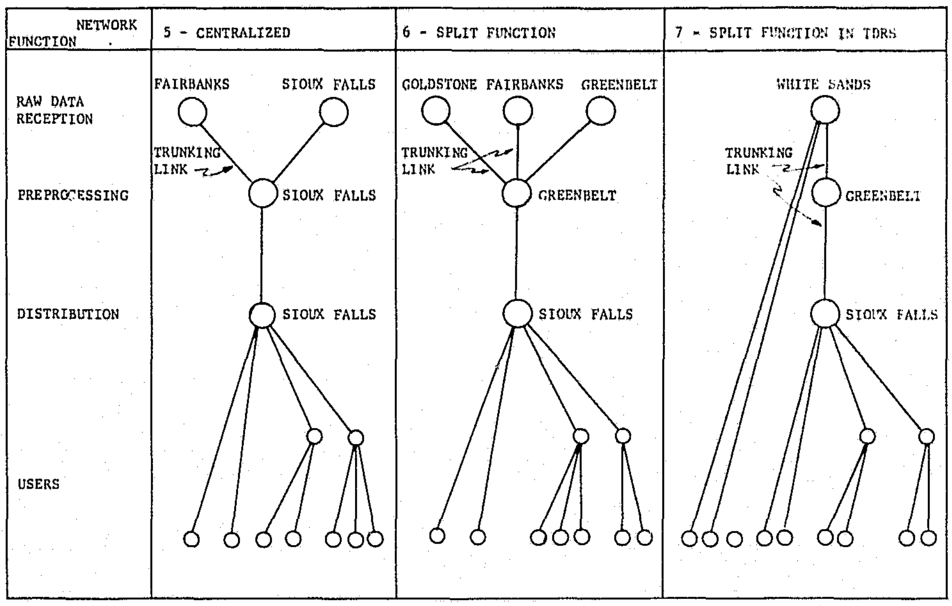


Figure 11-3. Centralized and Split Preprocessing/Distribution Networks

Figure 11-3 compares centralized configuration 5 with two other configurations currently under consideration by other groups in NASA. Configuration 6 is similar to that now in use on LANDSAT-A with the addition of a readout terminal at Fairbanks. Configuration 7 postulates the availability of the Tracking and Data Relay Satellite (TDRS),* with preprocessing performed at Greenbelt. Another configuration (not shown) uses TDRS and performs both preprocessing and distribution functions at Sioux Falls. The only difference between that configuration and configuration 7 is the absence of the trunk link between Greenbelt and Sioux Falls.

Figure 11-1 shows the possible existence of area centers. An area center would receive data from the preprocessing facility and then distribute it to individual users within its jurisdiction. As discussed in Section 8.4.4, such centers could reduce costs by consolidating communication and user-unique processing functions for a number of users with similar requirements located in relatively close proximity. All network modeling and cost analysis in this section, however, are based on data dissemination to each user directly from the preprocessing center(s).

11.3 Network Simulations.

Ninety simulation runs were made of the first five network configurations for various combinations of the following parameters, as tabulated in Tables 11-1 and 11-2: (1) 30m/7-band vs 10m/12-band ERS sensors, (2) nominal user demand vs expanded user demand, (3) different

*The use of TDRS for ERS raw data transmission is under consideration by NASA. Present plans place an upper limit of 300 Mbps on the TDRS channel capacity, limiting the resolution to 17.5m (7 bands) or to 22.9m (12 bands). Therefore, the 10m/12-band case would require development of a new wideband data relay satellite, probably operating in a higher millimeter or optical band.

Table 11-1

Lower-48-State Simulations

NETWORK	USER DEMAND	ERS RES/BANDS	PREPROCESSING SPEED(MIN/SCENE)	NUMBER TRANSPONDERS	TRANSMISSION RATE PER TRANSPONDER (MBPS)	NUMBER SIMULATIONS	OTHER PARAMETERS
#1 Regional ET Regional Preprocessor	Nominal	30/7	5, 15-17**	1	5.5 - 6.5	5	16-Hour Shift
	Expanded	30/7	11-17**	1	6 - 8	7	2 ERS @ 920 km
	Nominal	10/12	31*	3	40	1	Discrete user Xmission
	Expanded	10/12	31* 12 - 16**	3 - 6	40	8	
#2 Regional ET Central Processor	Nominal	30/7	15	1	10 - 50	4	(Same as above)
	Expanded	30/7	15	1	10 - 50	5	
	Nominal	10/12	11 - 18	3 - 4	40	4	
	Expanded	10/12	11 - 18	3 - 5	40	6	
#3 Central ET Central Processor	Nominal	30/7	15	1 - 6	1 - 6	4	(Same as above)
	Expanded	30/7	15	1	6 - 8	3	
	Nominal	10/12	15 - 17	3 - 4	40	4	
	Expanded	10/12	11 - 17	3 - 4	40	6	
#3 Central ET Central Processor Broadcast Mode	Expanded	30/7	15	1	2.5 - 6	3	16-Hour Shift 2 ERS @ 920 km Broadcast User Xmission
TOTAL NUMBER SIMULATIONS:						60	

* Per regional processor

** Divided according to load

Table 11-2

Lower-48-State and Alaska Simulations

NETWORK	USER DEMAND	ERS RES/BANDS	PREPROCESSING SPEED (MIN/SCENE)	NUMBER TRANSPONDERS	TRANSMISSION RATE PER TRANSPONDER (MBPS)	NUMBER OF SIMULATIONS	OTHER PARAMETERS
#4 Regional ETS (AK and SD) Regional Preprocessors (AK and SD)	Expanded	30/7	AK: 30, 15 SD: 10	1	3.7-4.75	6	16-hour shift 2 ERS @ 920Km Broadcast user transmission
#5 Regional ET's Central Preprocessor (SD)	Expanded	30/7	3.0-12.5	1	4.75-10.5	24	(Same as above)
TOTAL NUMBER OF SIMULATIONS						30	

preprocessing speeds, (4) different transponder link capacities, and (5) user-unique vs broadcast user data transmission.* The results are presented and compared below.

11.4 Simulation Results: Lower-48 States.

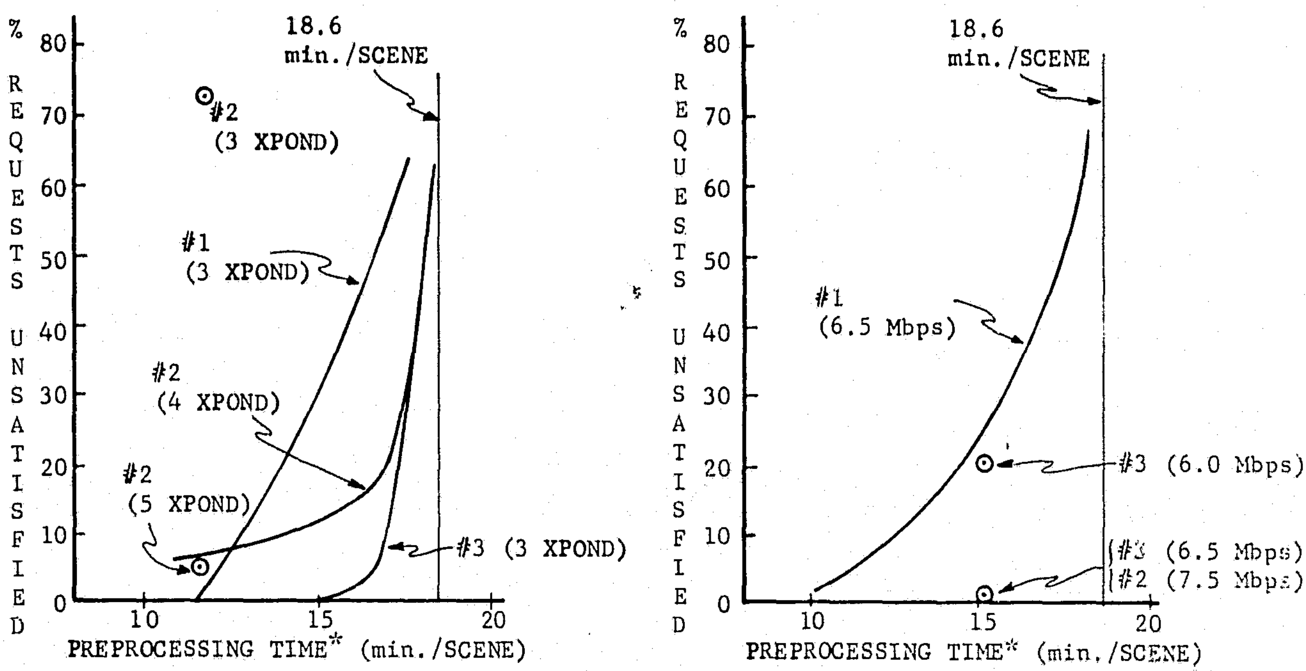
The results of the lower-48-states simulations show: (1) the superiority of the central-receiving/central-preprocessing network topology, (2) the existence of thresholds in both preprocessing speed (scenes per hour) and transponder transmission rate, both of which thresholds must be exceeded simultaneously or the response time of the network-to-user requests will become infinite, (3) the distinct advantage of broadcast over user-unique transmission, and (4) the impact on network parameters of nominal versus expanded user demand and of 30m/7-band versus 10m/12-band data.

11.4.1 Central Receiving/Preprocessing Most Efficient: The results of simulating network configurations 1, 2 and 3 may be compared by plotting the percentage of the user requests that are not delivered to the user (via a UOT satellite transmission system) within the user timeliness requirement versus the preprocessing time per scene with transponder transmission speed as a parameter. (A scene is defined to include all of the spectral bands.) The curves of Figure 11-4 result from consideration of the expanded user demand model with user-unique user data transmissions for 10m/12-band and for 30m/7-band ERS sensors. These figures are summarized in Table 11-3 which show the required preprocessor speed and transponder transmission speed for timely dissemination of all user requests for the three configurations. For completeness and ease of reference, Table 11-4 also summarizes a comparison presented in Section 11.4.3 of required preprocessing times per scene and transponder transmission speed for configuration 3 with user-unique vs broadcast user data transmission.

These results show the superiority of network 3; centralized receiving and centralized preprocessing. Network 2 requires trunking links which are not required in networks 1 and 3. Network 1 requires three preprocessors whereas only one is required in networks 2 and 3. Network 2 tends to satisfy the least number of users, everything else being equal. The poor performance of network 2 is believed to be caused by the additional load on the transponder which must handle the trunking of raw data as well as the transmission of preprocessed data to the users.

11.4.2 Computer and Transponder Throughput Requirements: On the average, the two-polar-orbit satellite data-collection model generates 51.7 scenes per day (coverage of the lower-48 states only). With two contiguous 8-hour shifts, this requires a preprocessing time throughput of 18.6 minutes/scene. This requirement is confirmed in Figure 11-4 where preprocessing times approaching this upper limit show increasing numbers of requests not satisfied. Pre-

*The distinction between these user data transmission alternatives is given in Section 11.4.3, Table 11-4.



10/12, EXPANDED DEMAND
(45.2 GIGABITS/SCENE)

30/7, EXPANDED DEMAND
(2.9 GIGABITS/SCENE)

* COMBINED TIME OF 3 REGIONS IN NETWORK #1

Figure 11-4. Percentage User Requests not Satisfied vs the Preprocessing Time for Coverage of the Lower-48 States Using Configurations 1, 2 and 3 (see Figure 11-1), with Transponder Transmission Speed as a Parameter.

Table 11-3

Required* Preprocessing Time and Transponder Transmission Speed With Lower-48-State Coverage Using the Expanded Demand Model

CONFIGURATION	10m/12-band ERS Sensor		30m/7-band ERS Sensor	
	PREPROCESSING TIME (min./scene)	TRANSPONDER TRANSMISSION SPEED (Mbps)	PREPROCESSING TIME (min./scene)	TRANSPONDER TRANSMISSION SPEED (Mbps)
ERS Reception/Preprocessing				
1. Regional/Regional (User-Unique)		110		6.5
Goldstone	39		42	
Sioux Falls	48		52	
Greenbelt	25		27	
2. Regional/Central (User-Unique)	10	130	15	7.5
3. Central/Central (User-Unique)	15	110	15	6.5
4. Central/Central (Broadcast)	--	--	15	3.0

* For all requests satisfied (i.e., delivered to user within specified user timeliness constraint)

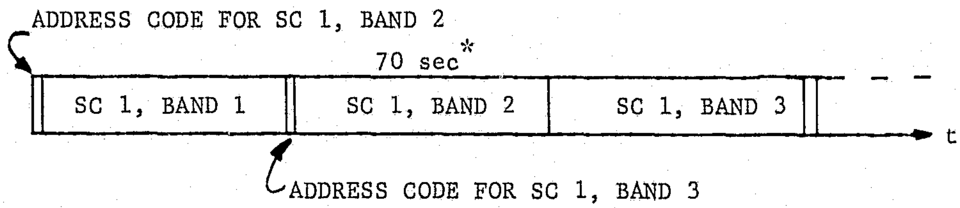
Table 11-4

Alternatives for User Data Transmission

- Unique User Transmission
  - Portion of Swath Requested by Each User Transmitted Sequentially:

  - Higher Priority to Users with Lower Timeliness Requirement
  - Same Data Transmitted More Than Once if User Swath Requests Overlap
  - Compatible with Terrestrial Link Network

- Broadcast Transmission
  - Complete Swath Broadcast to All Users Simultaneously



  - Each User Receives all Data and Stores Desired Data Only
    - Uses Address Header Transmitted at Beginning of Each Scene
  - Compatible with Communication Satellite Network

*6-Mbps data rate

processing times equal to or exceeding 18.6 minutes/scene create a steadily increasing preprocessor queue length and, ultimately, an infinite user-request response time.

A lower limit to the allowable values of transponder transmission speed is also evident from Figure 11-4, although its precise value for a particular configuration cannot thereby be accurately determined. With one of the Alaska configuration (#5) simulations, this limit was very carefully explored (see Figure 11-10).

11.4.3 Data Transmission Alternatives: Two modes of data transmission to the user were investigated: "User-unique transmission" and "broadcast transmission." User-unique transmission consists of transmitting to each user, in turn, all of the data he requested for each swath (see Table 11-4). Users with the shortest timeliness requirement are given highest priority.

This mode of data transmission proved inefficient because much of the data is transmitted more than once due to overlapping of areas requested. In the broadcast transmission mode, each scene is transmitted only once. All users wishing to receive that scene do so. As shown in Table 11-4, an address code is transmitted prior to each scene. Each user terminal

continuously monitors the signal transmitted from the communication satellite. When the address of a desired scene is received, automatic logic circuitry recognizes that address, starts up a tape recorder, and records the scene. (To provide time for tape recorder start-up, the address will actually be transmitted one scene ahead of the identified scene.)

Figure 11-5 compares the two modes of transmission. It is seen that the transponder data rate required to satisfy all users is reduced by approximately one-half by use of the broadcast transmission mode.

The broadcast mode is well suited for use with a domestic satellite which covers the entire area where users are located with its antenna beam. If the satellite used a multiple-beam antenna with narrower beamwidths, the broadcast mode described above would be modified.

11.4.4 Impact of User Demand: The effect of the expanded user demand over the nominal demand for both the 30m/7-band and 10m/12-band cases is illustrated in Table 11-5 using network 3. For the 30m/7-band case, the network sized for the nominal demand starts into saturation when required to handle the expanded demand -- 19.4% of the users do not meet their timeliness requirements. A small increase of the transponder capacity (from 6 to 7 Mbps) corrects this situation. Based on the average utilization of the transponder, it would be possible to deliver all requested data within the timeliness criteria with a transponder data rate of about 6.1 Mbps (7 x 0.87).

The 10m/12-band system simulation contained sufficient transponder capacity to handle the expanded demand. Both the average utilization of the transponders and the average age of the delivered data increased, however, as shown.

This shows that the network system parameters (and cost) are relatively insensitive to the choice between the two user models. Therefore, the expanded user model was used in most of the simulations.

This relative insensitivity to demand model may be used to introduce a conclusion that becomes even more readily apparent from simulations of networks 4 and 5, where broadcast user transmission is used (see Section 11.5.3): viz., if, in a particular network configuration, the parameters are sized to prevent network saturation (i.e., build-up of infinite queues for the preprocessor and/or the transponder), the data timeliness requirements will be satisfied automatically.

11.4.5 30m/7-band versus 10m/12-band Data: From Table 11-3, it is seen that, with very good accuracy, the effect on any given network of the 10m/12-band data is to increase the speeds required for preprocessing and transmission of 30m/7-band data in direct proportion

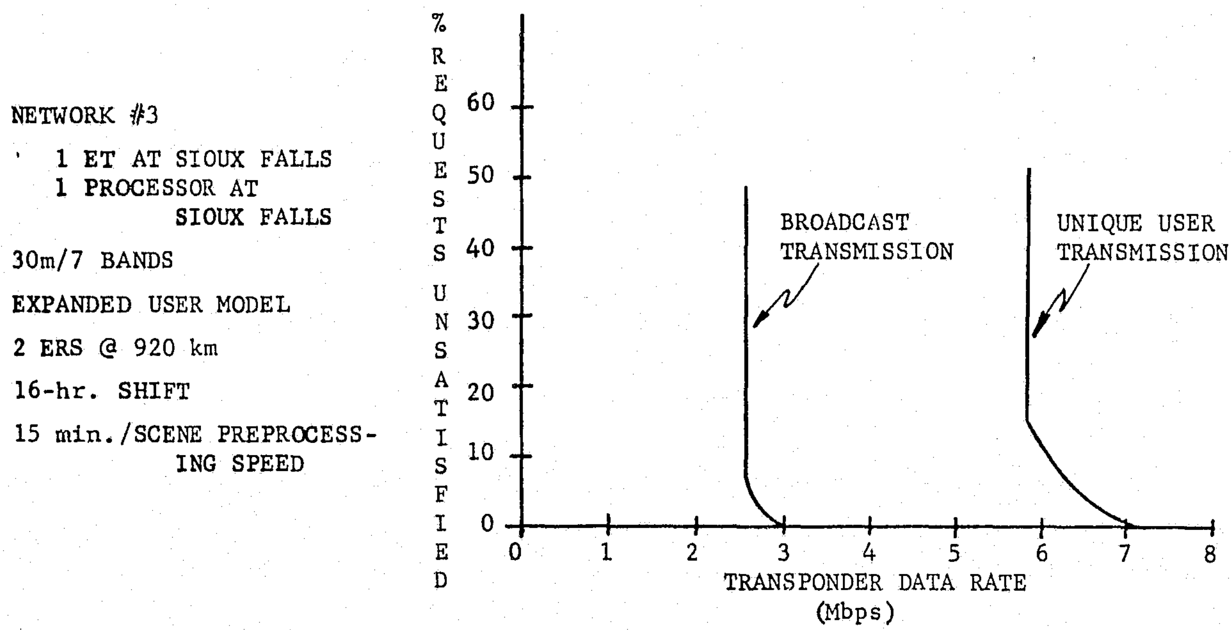


Figure 11-5. Comparison of Data Transmission Techniques to User

Table 11-5

Impact of User Demand

RES/ BANDS	USER DEMAND	REQUIRED(1) NUMBER TRANSPONDERS	REQUIRED(1) TRANSPONDER (Mbps)	AVERAGE UTILIZATION OF TRANSPONDER (%)	NUMBER REQUESTS (9 days)	REQUESTED* DATA VOLUME (9 DAYS) (gigabits)	AVERAGE AGE OF DELIVERED DATA (hrs.)
30/7	Nominal	1	6	97.5	225	3212	20.2
	Expanded	1	6(2)	100.0	420	3808	26.7
	Expanded	1	7	87.0	420	3808	13.7
10/12	Nominal	3	40	68.5	225	45955	11.6
	Expanded	3	40	89.5	420	51365	12.7

* i.e., the sum of all the user requests, including requests for identical or overlapping land areas. (Total data volume, independent of requests, for 9-day period from two ERS's is 1360 Gigabits and 2100 Gigabits for 30m/7-band and 10m/12-band data, respectively.)

(1) Required for 0% unsatisfied users.
(2) 6-Mbps transponder rate -- 19.4% unsatisfied users

Assumptions: Lower-48 states
2 ERS
#3 - Central ET, Central Processor
User-unique Transmission
15 minutes/scene preprocessing time

to the ratio of the total data volumes. This is evident for the tranponder data rates* -- the ratios of 110 Mbps/6.5 Mbps and 130 Mbps/7.5 Mbps, being approximately the same as the ratio of the down-link data rates (1579.2 Mbps/102.3 Mbps) for 10m/12-band and 30m/7-band data (see Section 3.2.3). For the preprocessor, it becomes evident when it is noted that, although the preprocessing time per scene remains constant, going from 30m/7-band to 10m/12-band data, the data volume per scene has increased, per force, by exactly the ratio of the total data volumes.

11.5 Simulation Results: Networks Including Alaska.

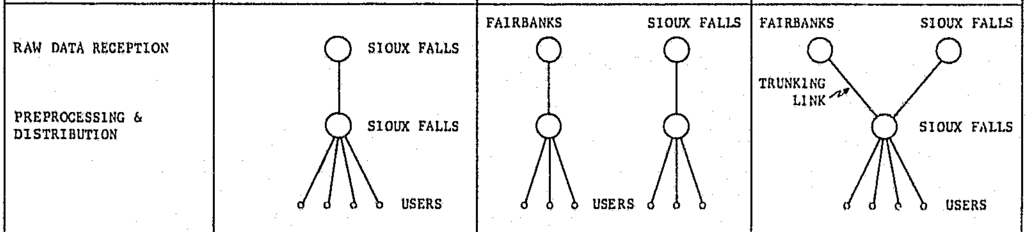
Simulations of networks 4 and 5 show the impact on network parameters of adding demand for Alaska data to the demand model, show there is no clear-cut advantage (not considering cost) to either network, describe the trade-off of transponder transmission rate for preprocessor speed for a given average age of delivered data, illustrate causes of network saturation, and indicate a dependence of buffer storage capacity on transponder rate and preprocessor speed. Having ruled out the necessity of further simulations with user-unique transmission (Section 11.4.3), with the nominal demand model (Section 11.4.4), or with 10m/12-band data (Section 11.4.5), these simulations are all restricted to broadcast user transmission, expanded user demand, and 30m/7-band data.

11.5.1 Impact of Alaska: When Alaska is added to the demand model, a central receiving location (as in network 3) is no longer possible for direct reception from the ERS's (see Figures 7-28 and 7-29). The choice of networks is, therefore, between one with regional preprocessing (#4) and one with central preprocessing (#5), both of which must use regional reception. The addition of Alaska increases the average data volume generated by approximately 50%. Figure 11-6 shows a comparison between network 3 and networks 4 and 5, where #4 and #5 include Alaska. In the latter case (network 5), the Sioux Falls preprocessor speed would have to be increased by 50% and a trunking link from Fairbanks to Sioux Falls would be added. In the former case, (network 4), a second preprocessor, half the speed of the Sioux Falls preprocessor, would have to be added at Fairbanks and the transponder data rate would need to be increased. The transponder data rate shown in Figure 11-6 is the total required for trunking plus user broadcast transmission. The transponder would be used on a time-shared basis between Fairbanks and Sioux Falls in network 4 and between the trunking and user transmission links in network 5. In the latter case, the trunking link was given priority over the user link.

11.5.2 Simulation Comparing Networks 4 and 5: Figure 11-6 also shows, of course, a comparison between networks 4 and 5. A definite superiority of one over the other is not apparent. Although regional preprocessing requires a lower transponder transmission rate

*The ratio of the data rates is equivalent to the ratio of the total (e.g., 9-day cycle period) data volume since the duration of each ERS pass is unaffected by the data rate.

30m/7BAND: EXPANDED USER DEMAND; BROADCAST MODE



	LOWER 48 - #3	LOWER 48 + ALASKA - #4		LOWER 48 + ALASKA - #5
		FAIRBANKS	SIOUX FALLS	
AVERAGE NUMBER REQUESTS/DAY	46.6	67.2		67.2
AVERAGE DAILY DATA VOLUME (Gbits)	151	74	151	225
MAXIMUM ALLOWED PRE-PROCESSING TIME (min./SCENE)	18.5	37.5	18.5	12.4
MINIMUM TRANSPONDER TRANSMISSION RATE REQUIRED (Mbps)	2.6	3.9		5.2

Figure 11-6. Impact of Alaska

than does central preprocessing, it also requires two preprocessors, albeit of slower individual speed, rather than one. Looking at the distributions of the age-at-delivery of individual user requests for approximately equivalent implementations (in terms of transmission and preprocessing capacities*) of networks 4 and 5 (Figure 11-7), slightly earlier delivery is seen for network 5. The average age of data delivered by these implementations of the two networks is 12.8 and 9.9 hours for #4 and #5, respectively. The longer average-time-to-delivery of network 4 is believed to be caused by the first-in-first-out queuing discipline used to time share the transponder. Two facts lend support to this belief. First, increasing both the transponder and the Fairbanks preprocessing capacity -- separately and then simultaneously -- had very little effect on the pattern of data deliveries versus time (see Figure 11-8), even though the average age of delivered data was reduced. In the best case, however, the average data age still exceeded that of network 5 by a little more than an hour. Second, increasing the speed of the Fairbanks preprocessor without increasing the transponder transmission rate caused late delivery of 2.2% of the user requests; whereas, before, all deliveries had been early. This is attributed to the queuing discipline as follows. The faster preprocessing of data received at Fairbanks now allows this data to reach the transponder queue ahead of (rather than after) some "shorter" timeliness data received at Sioux Falls. The Fairbanks data would, therefore, be transmitted first, delaying and causing late delivery of the shorter timeliness data.

*Transmission capacities of 4.2 Mbps (#4) and 5.8 Mbps (#5) are approximately 10% above the respective required minimum values. Parallel preprocessors (#4) with processing times of 15 and 30 min/scene are equivalent to a single preprocessor (#5) of 10 min/scene, since preprocessor speeds (the reciprocal of preprocessing time) add directly; i.e.,

$$\frac{15}{15} + \frac{1}{30} = \frac{1}{10}.$$

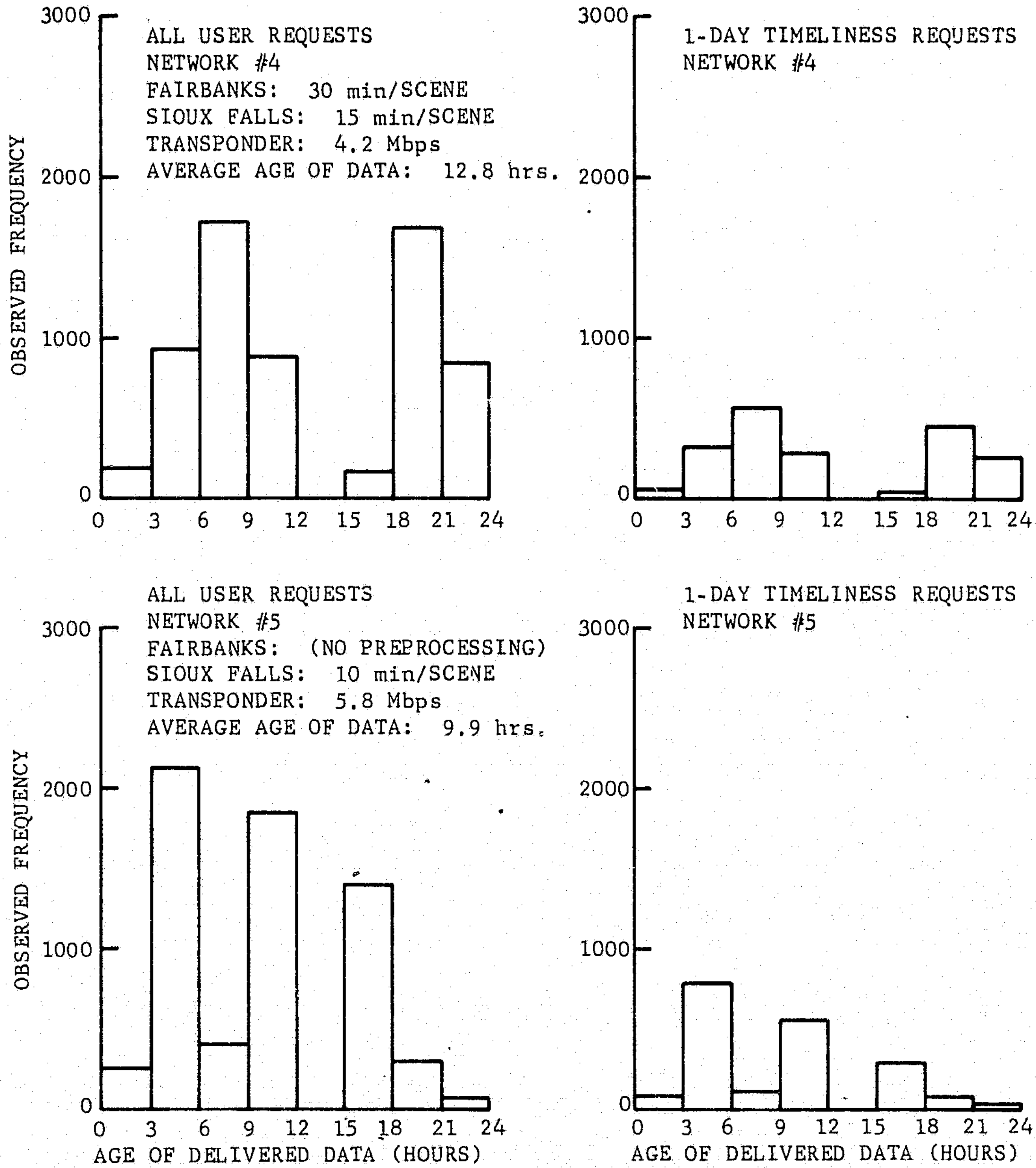


Figure 11-7. Observed Frequency of Delivery of Requested Data Vs Age of Requested Data at Delivery

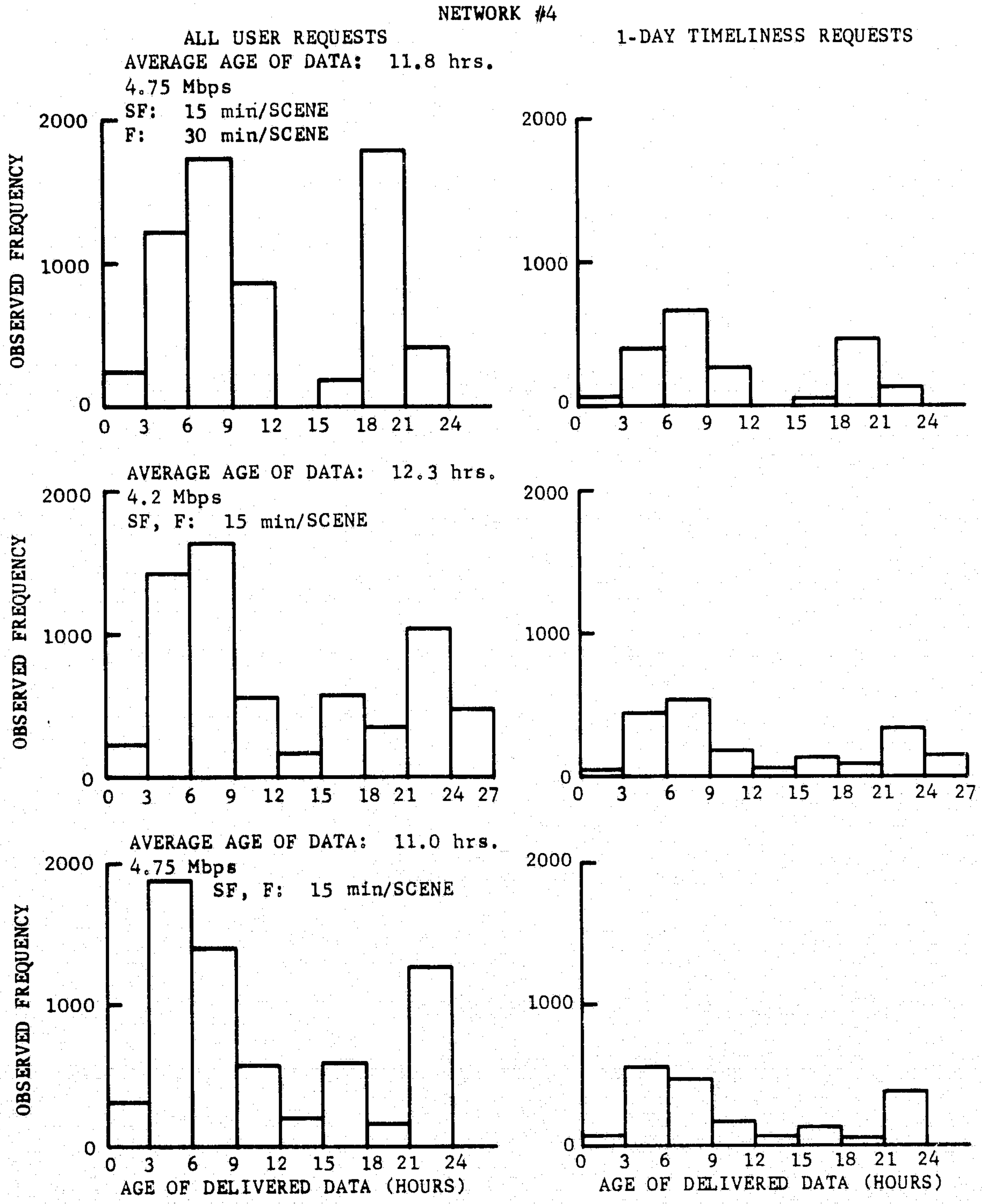


Figure 11-8. Observed Frequency of Delivery of Requested Data Vs Age of Requested Data at Delivery For Network #4

A series of simulations underlies the parameter values given in Figure 11-6 for networks 4 and 5. Some results from these simulations are presented in Tables 11-6 and 11-7 and Figure 11-9. An important fact to be noted from Figure 11-9 is the sharpness of the threshold for total transponder transmission rate. The transition region between all-user-requests satisfied and no-user-requests satisfied (i.e., network saturation) is very narrow. (Unsatisfied requests are those that do not arrive within the user-specified timeliness criterion.) This phenomenon is believed to be associated with broadcast user transmission, and may be contrasted with the more gradual degradation in network performance with reduction in preprocessing speed and transponder transmission rate when user-unique transmission is used (see Figures 11-4 and 11-5).

11.5.3 Average Age of Delivered Data and Network Capacity: Computer simulations of network 5 were made to determine the average age of delivered data (from time of data arrival at the readout station to time data is received by the user). Selected results from these simulations are given in Table 11-6. The average data age is a function of both preprocessing speed and transponder capacity. Figure 11-10 shows the relationship between these parameters. This figure clearly illustrates the conclusion first introduced in Section 11.4.4 that, if preprocessing speed and transponder capacity are sufficient to keep up with the data generated by the earth-resources satellites, then the average age of the delivered data will be small and user timeliness criteria will be met. Sufficiency of capacity, in this instance, means a transponder throughput rate greater than 5.2 Mbps and, simultaneously, a preprocessing time less than 12.46 min/scene.

11.5.4 Network Saturation: Progressive network saturation, or overload, due either to insufficient transponder capacity or to excessive preprocessing time is shown in Table 11-8. In the first simulation shown there, the 4.75-Mbps transponder transmission rate is less than the minimum allowed 5.2 Mbps. As a result, weekly snapshots of system status over the 35-day simulation period record marked and continued deterioration in system performance (average age of delivered data and percentage of user requests unsatisfied). The cause is easily seen to be the steady increase in the length (i.e., contents) of the transponder queue and the resulting increase in the average time an individual request spends in the transponder queue.

In the second simulation, the 12.5 min/scene preprocessing time just barely exceeds the allowed maximum time of 12.46 min/scene. Consequently, the associated deterioration in system performance is not as rapid as in the first simulation. Nevertheless, given sufficient time, the preprocessor queue length would become infinite. The third simulation merely confirms that, when both transmission rate and preprocessing speed are above their respective thresholds, even slightly, the network will not saturate though system performance may not be perfect.

The main objective, then, becomes one of establishing adequate margin in the design, especially in buffer storage capacity, to insure the system does not overload.

Table 11-6
Computer Simulations of Network #5
(Broadcast User Transmission, Expanded User Model, 30m/7-Band Data)

PROCESSING TIME (min/SCENE)	TRANSPONDER RATE (Mbps)	AVERAGE AGE (hrs)	% UTILIZATION PREPROCESSOR	% UTILIZATION TRANSPONDER	% USERS UNSATISFIED	CONTENTS							
						PREPROCESSOR QUEUE***				TRANSPONDER QUEUE***			
						No. SWATHS			%0's	No. SWATHS			$0's
						M	C	A		M	C	A	
12.5	4.75	76.7†*	99.99	100.00	57.6	6	2	2.03	0.3	41	40	19.70	0
12.5	5.25	17.0†	99.99	98.58	7.9	6	2	2.05	0.3	4	3	1.38	5.6
12.5	6.30	14.3†	99.99	82.20	6.0	6	2	2.03	0.3	4	0	0.47	27.3
12.5	10.50	12.6†	99.99	49.42	4.3	7	2	2.08	0.3	3	0	0.08	63.8
11.5	4.75	76.8*	93.03	100.00	58.0	4	0	0.80	12.5	43	43	21.30	0
11.5	5.25	14.1	93.03	99.12	2.5	4	0	0.80	12.5	4	3	2.00	2.6
11.5	5.80	11.1	93.03	90.13	0	4	0	0.90	12.5	4	1	1.13	15.2
11.5	6.30	9.9	93.03	82.42	0	5	0	0.90	12.5	4	0	0.72	20.0
11.5	10.50	7.7	93.03	49.53	0	5	0	0.90	12.5	3	0	0.12	55.4
10.7	4.75	76.3*	86.52	100.00	57.7	4	0	0.61	12.9	44	44	21.65	0
10.7	5.25	13.3	86.52	99.15	0.6	4	0	0.62	12.5	5	4	2.29	2.6
10.7**	5.80	12.0	86.52	89.97	0	4	1	0.42	11.8	4	3	0.76	15.6
10.7	6.30	9.3	86.52	82.56	0	4	0	0.65	12.5	4	1	1.07	19.7
10.7	10.50	6.5	86.52	49.62	0	4	0	0.74	12.5	3	0	0.14	51.8
10.0	4.75	75.7*	80.76	100.00	56.9	4	0	0.48	16.3	45	44	21.67	0
10.0	5.25	12.8	80.76	99.16	0	4	0	0.48	20.7	5	4	2.39	3.5
10.0	5.80	9.9	80.76	90.09	0	4	0	0.51	13.9	5	3	1.59	16.4
10.0	6.30	8.6	80.76	82.56	0	5	0	0.54	13.9	4	2	1.08	18.3
10.0	6.85	7.6	80.76	76.24	0	4	0	0.56	13.2	4	0	0.73	20.1
10.0	10.50	5.3	80.76	49.68	0	4	0	0.62	12.5	3	0	0.14	47.3
7.5	4.75	74.8*	60.57	100.00	56.3	2	0	0.20	41.0	45	43	21.74	0
7.5	5.80	8.3	60.57	90.13	0	2	0	0.21	37.0	5	1	1.44	12.9
7.5	6.85	5.7	60.57	76.42	0	2	0	0.22	30.9	5	0	0.73	19.4
3.0	4.75	73.1*	24.22	100.00	54.3	1	0	0.00	92.2	45	43	21.70	0
3.0	10.50	1.8	24.22	49.68	0	1	0	0.01	92.9	2	0	0.11	46.8

† Length of queue for preprocessor increasing toward infinity.

* Length of queue for transponder increasing toward infinity.

** Data point not shown in Figure 11-7. Simulation statistics registers were not zeroed prior to run.

*** M = maximum contents; C = current contents; A = average contents; %0's = percentage of all preprocessed or transmitted data that had zero time in queue.

Table 11-7

Computer Simulations of Network #4

(Broadcast User Transmission, Expanded User Model, 30m/7-Band Data)

PREPROCESSING TIME (min / SCENE)		TRANSPONDER RATE (Mbps)	AVERAGE AGE (hrs)	% UTILIZATION PREPROCESSOR		% UTILIZATION TRANSPONDER	% USER REQUESTS UNSATISFIED	CONTENTS											
								PREPROCESSING QUEUE**								TRANSPONDER QUEUE**			
								Sioux Falls				Fairbanks							
								No. SWATHS			%0's	No. SWATHS			%0's	No. SWATHS			%0's
Sioux Falls	Fairbanks			SF	F			M	C	A		M	C	A		M	C	A	
15	30	3.70	46.4*	81.6	78.8	100.00	44.1	3	0	0.59	21.5	3	0	0.60	32.6	23	23	11.0	0
15	30	4.20	12.8	81.6	78.8	93.4	0	3	0	0.59	21.5	3	0	0.60	32.6	3	2	0.68	25.9
15	30	4.75	11.8	81.6	78.8	83.0	0	3	0	0.59	21.5	3	0	0.60	32.6	3	2	0.47	40.5
15	15	3.70	46.7*	81.6	39.5	100.00	43.6	3	0	0.59	21.5	3	0	0.16	35.6	24	24	11.8	0
15	15	4.20	12.3	81.6	39.5	93.4	2.2	3	0	0.59	21.5	3	0	0.16	35.6	4	2	1.27	16.0
15	15	4.75	11.0	81.6	39.5	83.0	0	3	0	0.59	21.5	3	0	0.16	35.6	4	2	0.95	25.7

* Length of queue for transponder increasing toward infinity.

** M = maximum contents; C = current contents; A = average contents; %0's = percentage of all swaths with zero time in queue.

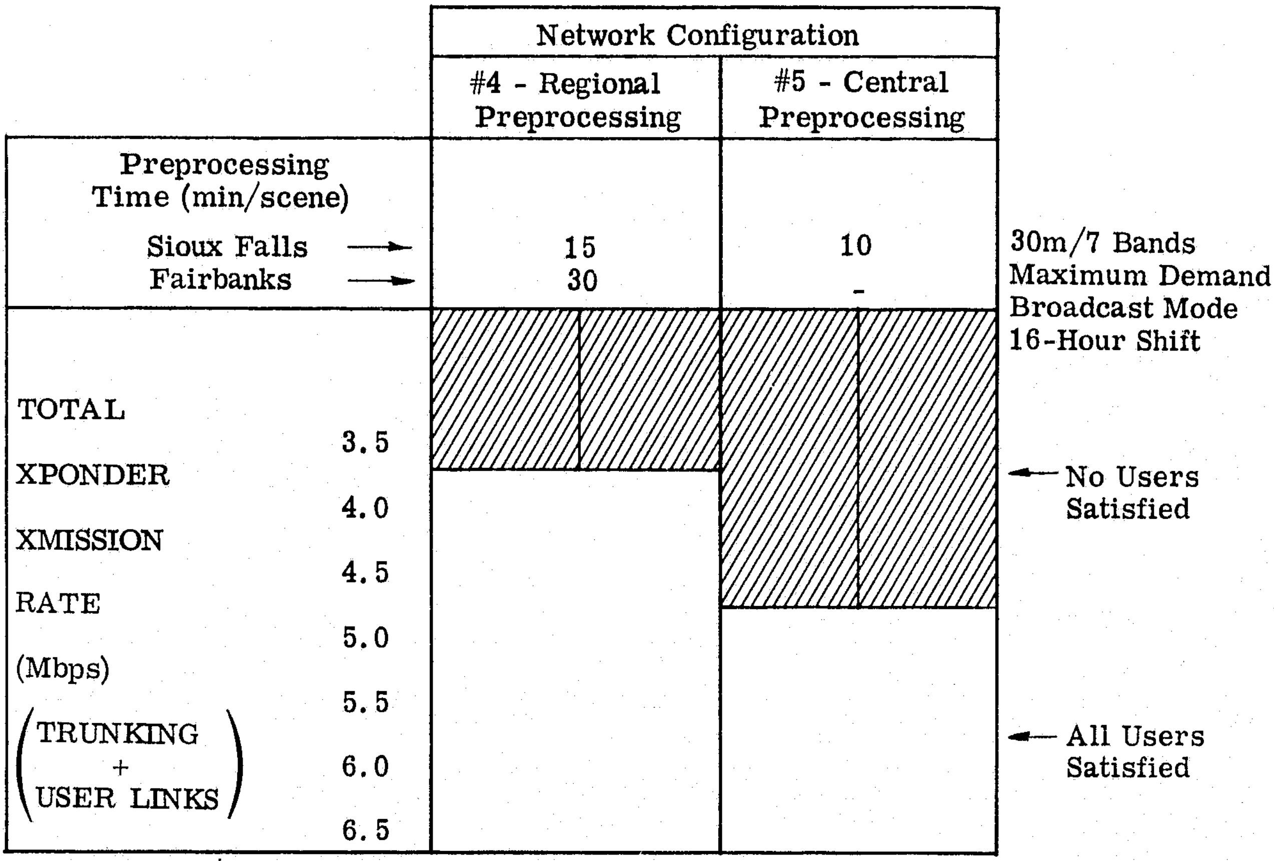


Figure 11-9. Performance of Sioux Falls/Fairbanks Network

11.5.5 Buffer Storage Capacity: Not surprisingly, transmission and preprocessing capacities of a network have some influence on the amount of buffer storage required in the transmission and preprocessing queues. The interaction of these functions for network 5 may be illustrated in reference to the five simulations that use a preprocessing time of 11.5 min/scene (see Table 11-6). As the transponder transmission capacity is increased, there are two offsetting effects as far as total required storage capacity is concerned. First, the transponder queue length is reduced, going from a maximum of 4 swaths to 3 swaths. Second, the preprocessor queue length is increased because transfer of raw data to the preprocessor queue from Alaska is more rapid. The maximum contents increases from 4 swaths to 5 swaths. Notice that, for a transmission speed of 6.3 Mbps, the total storage capacity is at a maximum of 9 swaths.

Looking now at the five runs using a 10.7 min/scene preprocessing time, it is seen that the maximum contents of the preprocessor queue is now only 4 swaths, whereas, with the slower 11.5 min/scene preprocessor, the maximum contents of the queue reached 5 swaths. At the same time, as anticipated, the maximum contents of the transmission queue (for 5.25 Mbps) has increased from 4 swaths to 5 swaths. That is, until such time as the combined capacities of the preprocessor and the transponder allow reception, preprocessing, and broadcast of an

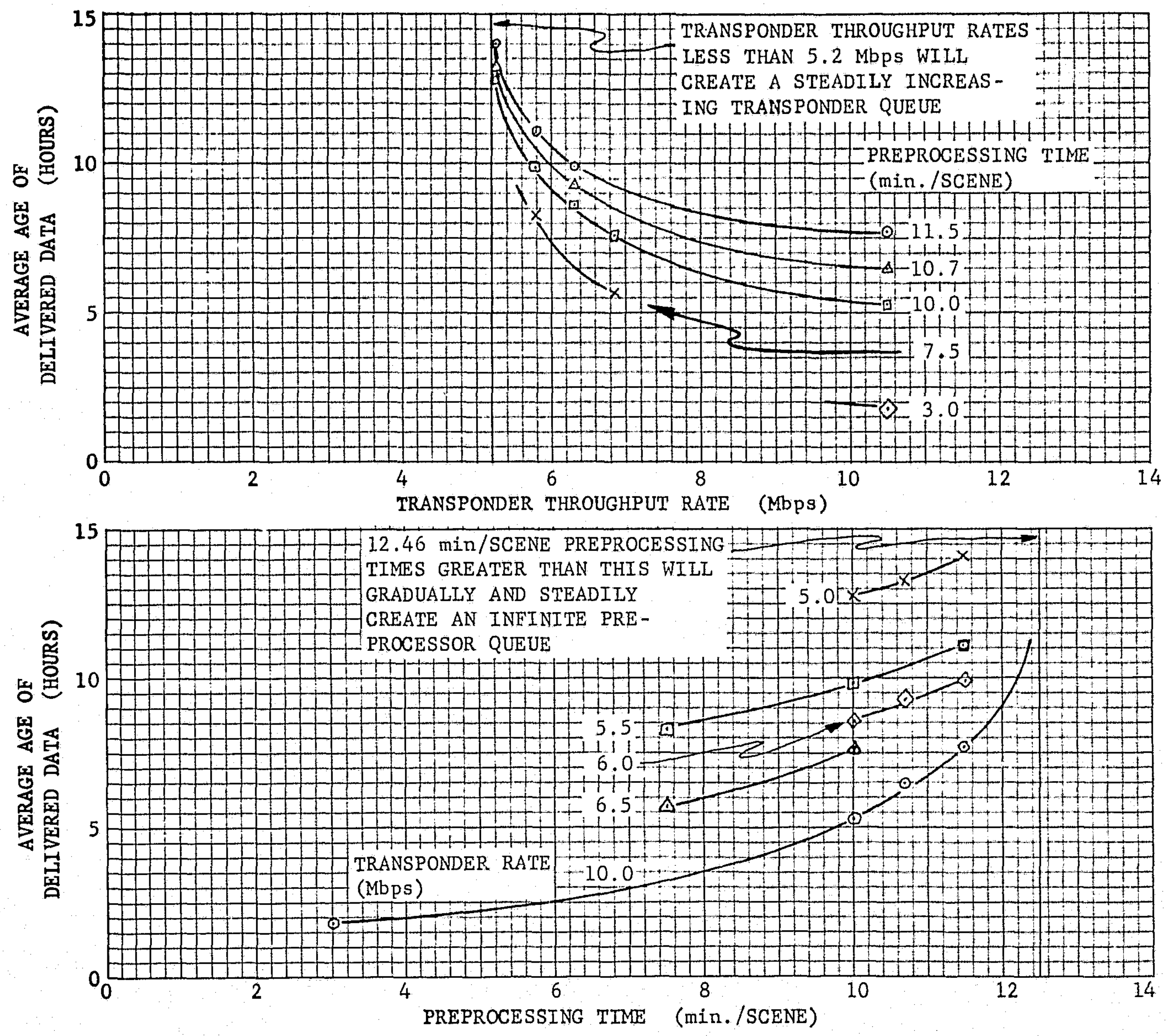


Figure 11-10. Effect of Transponder Rate and Preprocessing Time On Average Age of Delivered Data. (All simulations shown here resulted in 100% user satisfaction. All requests were delivered within the user-specified timeliness criterion.)

average-length swath prior to reception of the succeeding swath, the faster data is preprocessed, the more time it will spend in the transmission queue.

Table 11-8

Three Simulations of Network #5 Showing The Progressive Network Saturation
Caused by Insufficiency of Transponder Rate or Preprocessing Speed
(Broadcast User Transmission, Expanded User Model, 30m/7-Band Data)

Simulation 1: 11.5 min./Scene, 4.75 Mbps (Insufficient Transponder Rate)

Day	TRANSPONDER QUEUE* LENGTH (No. of Swaths)						PREPROCESSOR QUEUE* LENGTH (No. of Swaths)					Average Age (Hours)	% Unsat.
	Max	Avg	Cur	%0's	Total Avg Time (Hrs)		Max	Avg	Cur	%0's	Total Avg Time (Hrs)		
7	14	6.0	13	0	19.0		4	0.5	0	13.8	2.5	35.6	28.7
14	22	10.1	22	0	25.8		4	0.65	0	12.7	2.5	44.9	43.3
21	29	14.0	29	0	33.2		4	0.73	0	12.4	2.6	55.0	49.7
28	37	17.7	34	0	40.4		4	0.77	2	12.7	2.6	65.9	53.1
35	43	21.3	43	0	47.3		4	0.80	0	12.5	2.6	76.8	58.0

Simulation 2: 12.5 min./Scene 10.5 Mbps (Excessive Preprocessing Time or Insufficient Preprocessing Speed)

7	2	0.05	0	67.5	0.16		5	0.98	1	1.7	4.84	10.5	0
14	3	0.07	0	64.3	0.19		5	1.37	1	0.9	5.3	10.8	1.0
21	3	0.08	0	62.8	0.18		6	1.65	2	0.6	5.8	11.3	1.2
28	3	0.08	0	63.9	0.18		6	1.89	2	0.4	6.3	11.9	2.8
35	3	0.08	0	63.8	0.19		7	2.08	2	0.3	6.8	12.6	4.3

Simulation 3: 11.5 min./Scene, 5.25 Mbps (Capacity Sufficient to Prevent Network Overload)

7	4	1.33	2	1.2	4.4		4	0.52	0	13.8	2.6	13.6	2.8
14	4	1.73	4	2.9	4.5		4	0.68	0	12.7	2.6	13.7	2.6
21	4	1.87	3	2.7	4.5		4	0.77	0	12.4	2.7	13.9	2.2
28	4	1.93	2	3.2	4.5		4	0.82	2	12.7	2.7	13.7	2.2
35	4	2.04	3	2.6	4.6		4	0.83	0	12.5	2.7	14.1	2.5

* Max = maximum, Avg = Average, Cur = Current, %0's = the percent of swaths with zero time in queue.

11.6 Network Cost Comparisons.

The seven network configurations described in Section 11.2 were sized to satisfy all user requirements. The 30m/7-band case and the expanded user demand model were postulated. These configurations are shown in Table 11-9. Two cases were considered for network 3; one using user-unique transmission, the other using broadcast transmission. The annual costs were determined for each network and are shown on the last line of the table.

Table 11-9

Summary - Network Comparisons

2 ERS 30 m/7 BANDS EXPANDED DEMAND 16-HOUR SHIFT	LOWER 48				LOWER 48 + ALASKA			
	1	2	3 A	3 B	4	5	6	7
CONFIGURATION	GD SF GR	GD SF GR SF	SF SF		A SF	A SF SF	A GD GR GR SF	TDRS GR SF
DISSEMINATION	UNIQUE USER			BROADCAST MODE				
TRANSPONDER DATA RATE Mbps	6.5	7.5	6.5	3.0	4	6	8	8
PREPROCESSING SPEED min/SCENE	27 42 52	15	15	15	30 15	10	10	10
TOTAL ANNUAL COST, $K/yr	4829	4043	2352	2250	4024	3046	4432	2985

NOTE: USER-OWNED EQUIPMENT AND TDRS COSTS NOT INCLUDED

In comparing these costs, two facts should be noted: First, networks 1, 2 and 3 collect data from the lower-48 states only. Second, network 7 does not include any costs associated with the use of the TDRS (other than the cost of special digital-handling equipment at White Sands).

Tables 11-10, 11-11 and 11-12 present the breakdown of cost data. Costs above the line are for equipment procurement and installation. Development costs and other non-recurring costs, such as preparation of documentation, are not included. Costs of redundant equipment and facilities (buildings, land) also are not included.

Table 11-10

Cost Comparison of Lower-48-States Network

2 ERS 30m/7-bands Expanded Demand 16-hour shift	#1	#2	#3A	#3B
ERS Reception →	REGIONAL	REGIONAL	CENTRAL	
Preprocessing →	REGIONAL	CENTRAL	CENTRAL	
	USER-UNIQUE TRANSMISSION			BROADCAST
	EQUIPMENT & INITIAL INSTALLATION COSTS ($K)			
EQUIPMENT				
ERS DATA RECEPTION - THROUGH Q-L EXTRACTION	2823	2823	941	941
PREPROCESSING	3812	2550	2550	2550
POST-PROCESSING	465	155	155	155
TRUNKING (DOMSAT ET's)	186*	247**	62*	62*
TOTAL EQUIPMENT	7294	5775	3708	3708
EQUIPMENT HANDLING (10%)	729	578	371	371
INTEGRATION, INSTALLATION & TEST (20%)	1605	1270	816	816
PROFIT (10%)	963	762	489	480
TOTAL INITIAL INSTALLED COST	10591	8385	5384	5384
	ANNUAL COSTS ($K)			
Amortization (of initial installed cost: 7 yrs, 8% int.)	2034	1611	1034	1034
Maintenance (10% Total Equipment)***	733	590	375	375
Transponder (Leased)	204	230	204	102
Operation and Administration	1858	1612	739	739
TOTAL ANNUAL COST	4829	4043	2352	2250

* Transmit-only terminals. ** 3 Transmit-only and 1 Transmit-Receive Terminal
*** Includes an additional $4K for each Trunking ET (See Section 7.2.2.9)

Table 11-11

Cost Comparison of Alaska-Plus-Lower-48-States Networks

2 ERS 30m/7-bands Expanded Demand 16-hour shift Broadcast User Transmission	#4	#5
ERS Receiving →	REGIONAL	REGIONAL
Preprocessing →	REGIONAL	CENTRAL
	EQUIPMENT AND INITIAL INSTALLATION COST ($K)	
EQUIPMENT		
ERS DATA RECEPTION - THROUGH Q-L EXTRACTION	1882	1882
PREPROCESSING	4350	2835
POST-PREPROCESSING	310	155
TRUNKING (DOMSAT ET's)	124*	185**
TOTAL EQUIPMENT	6666	5057
EQUIPMENT HANDLING (10%)	667	506
INTEGRATION, INSTALLATION & TEST (20%)	1467	1113
PROFIT (10%)	880	668
TOTAL INITIAL INSTALLED COST	9679	7344
	ANNUAL COSTS ($K)	
Amortization (of initial installed cost: 7 yrs, 8% int.)	1859	1411
Maintenance (10% Total Equipment)***	675	514
Transponder (Leased)	132	190
Operation and Administration	1358	1031
TOTAL ANNUAL COST	4024	3046

* Transmit-only terminals. ** 1 Transmit-only and 1 Transmit-Receive Terminal. ***Includes an additional $4K for each Trunking ET (See section 7.2.2.9)

Table 11-12

Cost Comparison with Preprocessing at Greenbelt, Distribution at Sioux Falls

Includes Alaska 2 ERS 30m/7-bands Expanded Demand 16-hour shift Broadcat User Transmission	ERS Reception → Preprocessing →	#5 REGIONAL SIOUX FALLS	#6 REGIONAL GREENBELT	#7 TDRS GREENBELT
		EQUIPMENT AND INITIAL INSTALLATION COSTS ($K)		
EQUIPMENT				
ERS DATA RECEPTION - THROUGH Q-L EXTRACTION		1882	2823	616*
PREPROCESSING		2835	2835	2835
POST-PREPROCESSING		155	155	155
TRUNKING (DOMSAT ET's)		185**	370**	308**
	TOTAL EQUIPMENT	5057	6183	3914
EQUIPMENT HANDLING (10%)		506	618	391
INTEGRATION, INSTALLATION & TEST (20%)		1118	1361	861
PROFIT (10%)		668	816	517
	TOTAL INITIAL INSTALLED COST	7344	8978	5683
		ANNUAL COSTS ($K)		
Amortization (of initial installed cost: 7 yrs,8% int)		1411	1724	1092
Maintenance (10% Total Equipment)***		514	634	403
Transponder (Leased)		190	242	242
Operation and Administration		1031	1832	1248
TOTAL ANNUAL COST		3046	4432	2985

* Does not include cost of TDRS service. ** Transmit-only and Transmit-Receive Terminals
*** Includes an additional $4K for each Trunking ET (See Section 7.2.2.9)

11.6.1 Initial Installed Network Costs: ERS data reception covers the cost of the data readout terminal, including the antenna, the receiver, demodulator, buffer storage, reformatting, address insertion, and quick-look extraction (see Section 7.1.1.6 and 9.4.1). Networks 1, 2 and 6 require three readout terminals; networks 4 and 5 require two, and network 3 requires one. Network 7 is also a single installation located at White Sands and includes everything except the antenna and receiver. (An interface at IF is assumed.) A single ERS data-reception station costs about $940K.

Preprocessing covers all radiometric and geometric correction equipment plus auxiliary buffer storage, displays, etc., as detailed in Section 9.4.1. The costs are a function of preprocessing time per scene being about $2.55M for a time of 15 min/scene and $2.84M for a time of 10 min/scene. Network 1 requires three preprocessing facilities, network 4 requires two, and the others only one.

Post-preprocessing covers the cost of archive recording/playback, source selection, and interface control equipment. One set of equipment is located with each preprocessing facility.

Trunking/dissemination requires either transmit-only or transmit-only and transmit-receive trunking terminals. A transmit-receive trunking terminal consists of a limited-motion 5m antenna, 500W transmitter, 120°K low-noise preamplifier, receiver demodulator, and miscellaneous equipment. Total equipment cost for a single transmit-receive terminal is $123K and for a single transmit-only terminal is $62K (see Table 7-21).

Equipment handling costs are estimated to be 10% of the equipment costs and integration, installation, and test costs are estimated to be 20% of both handling and equipment costs. Profit is estimated at 10% of the total of these costs, thus completing the itemization of initial installed cost of the various networks.

11.6.2 Annual Network Costs: Initial installed network costs are converted to an equivalent annual cost, assuming a 7-year equipment life (amortized over 7 years) and an 8% interest rate. Annual maintenance costs are estimated to be 10% of the initial equipment costs, not including handling. (Maintenance of the trunking terminals includes an additional $4K as discussed in Section 7.2.2.9. See also Table 7-19.) The leased Domsat transponder cost is based on a nominal $800K per year per 40-Mbps charge (see Figure 7-14). Operations costs are based on personnel assigned for each shift to perform the functions shown in Table 11-13. Two shifts (16 hours per day), seven days a week are assumed. Total personnel costs are shown in Table 11-14 for each network configuration. They are given in detail in Section 9.4.2. Administrative costs are included in the personnel costs, being estimated at 15% of the total base salary.

Table 11-13

Operational Personnel for Data Dissemination Network

A. OPERATIONAL ENGINEER - acquisition, monitors BER, maintains rf equipment, operates data handling console, changes primary record tapes, maintains digital equipment.

B. PROCESSING ENGINEER - operates and controls correction operations, maintains equipment.

C. DATA DISSEMINATION ENGINEER - controls transmission from pipelines, archives and quick-look, changes quick-look and archive tapes.

D. CLERK - responsible for typing, reproduction, etc., assists in maintaining archive file, retrieves and shelves archive tapes (day shift only).

E. TECHNICIAN - performs minor trouble-shooting and repairs.

Table 11-14

Network Total Annual Personnel Cost and Cost Breakdown by Facility Type*

FACILITY TYPE AND COMBINED 2-SHIFT ANNUAL PERSONNEL COST	NETWORK CONFIGURATION						
	#1	#2	#3	#4	#5	#6	#7
CENTRAL - $739K reception, preprocessing and dissemination		1	1	1	1		
REGIONAL - $619K reception, preprocessing and dissemination	3			1			
CENTRAL - $664K reception and preprocessing						1	1
REGIONAL - $292K reception or dissemination only		3			1	4	2
TOTAL ANNUAL PERSONNEL COST ($K)	1858	1612	739	1358	1031	1832	1248

* The detailed costs of personnel for each facility type are given in Section 9.4.2

11.6.3 Sensitivity to Preprocessing Costs: As mentioned in Section 9.4, rapid changes in the state-of-the-art of digital processing hardware and software make cost estimates for these components less reliable than those for other components. It is appropriate, therefore, to determine the sensitivity of the total annual cost of the networks to variations in the estimated cost of the preprocessing equipment. Figure 11-11 presents the results of this determination in which the cost of the preprocessing equipment was assumed to vary from 0.5 to 1.5 times the nominal estimates given in Tables 11-10 through 11-13.

In reading Figure 11-11, networks 1, 2 and 3, which do not include Alaska, should be interpreted separately from the other 4 networks. The curves show that even a ± 50% error in the preprocessing cost estimate does not change the relative order of the three lower-48-state networks (1,2,3). The order of the lower-48-plus-Alaska networks (#4, #5, #6, #7) is changed slightly only if the nominal equipment cost estimate proves to be low. In this case, network 4 would become slightly more costly than network 6. Networks 5 and 7, however, continue to be the least-cost choices regardless of the cost of the preprocessing equipment. It is interesting to note that the cost difference between networks 4 and 5 decreases with decreasing preprocessing costs. A crossover would occur when the dual processing facilities of network 4 becomes less costly than the trunking link of network 5.

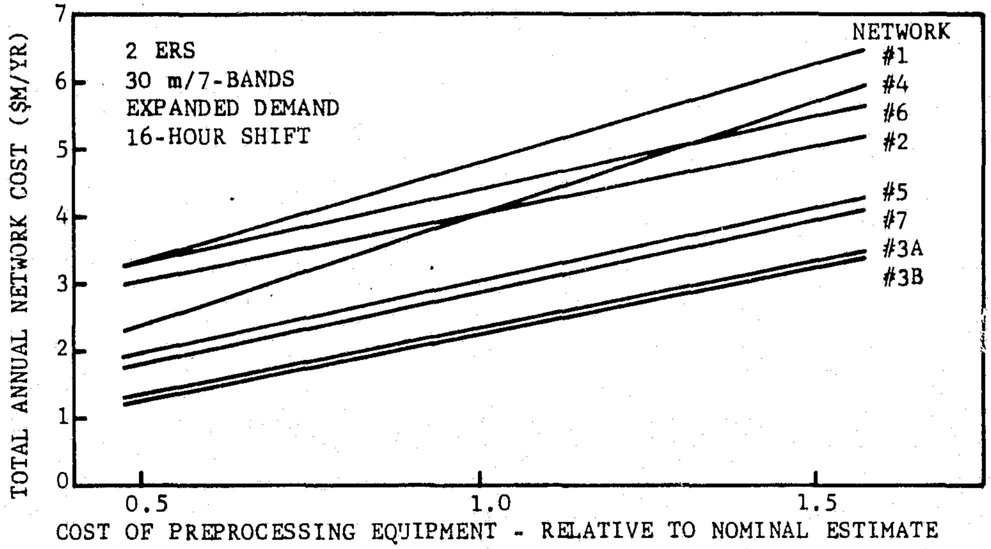


Figure 11-11. Network Costs Vs Preprocessing Costs

Note: Networks #1, #2, #3 cover lower-48 states only, others include Alaska.

Sensitivity to Operations Costs: The cost of network operations developed in Section 9.4.2 and summarized in Table 11-14 are believed to be minimum estimates and, as such, subject to increase. Were they to increase, the new amounts for the various networks would retain their relative ranking (e.g., operations cost for network 6 would still be more than for network 1, that for network 1 would still be more than for network 2, etc.) Since this ranking is the same, with one exception,* as the ranking of networks by total annual cost prior to the increase in operations costs (compare Tables 11-9 and 11-14), such an increase would not change the annual cost ranking. The results and conclusions of this study are, therefore, transparent to upward changes in the costs of operations.

11.6.5 Cost of 10m/12-Band Data Networks: Detailed cost estimates for the 10m/12-band case were not attempted because of the rather large extrapolations in the state-of-the-art required (see Section 12). Figure 11-12 presents an approximate extrapolation from the cost figures described above for networks 1 through 5 based on the reasoning shown in Table 11-15. The main difference between the two cases is the cost of data transmission which is expected to increase more rapidly than the cost of preprocessing, thus magnifying the advantage of the broadcast mode over the user-unique transmission mode (network 3B vs 3A). No development costs were included in this comparison.

*Networks 5 and 7 interchange rankings when ranked by total annual cost. This interchange could be reversed only if operations costs increased nearly 200%.

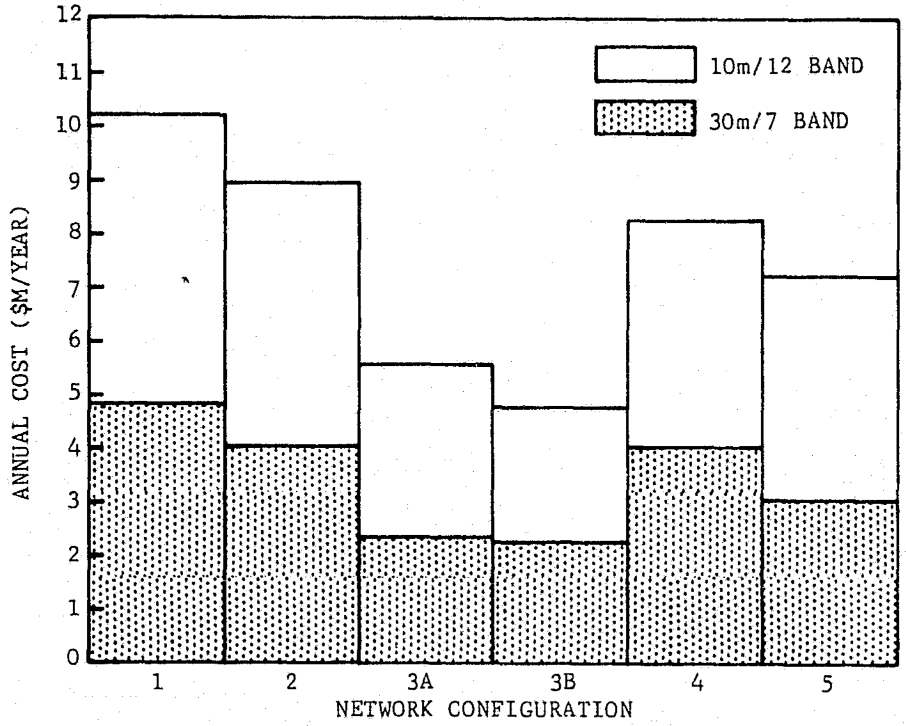


Figure 11-12. Comparison of 30m/7-Band and 10m/12-Band Annual Costs

Table 11-15

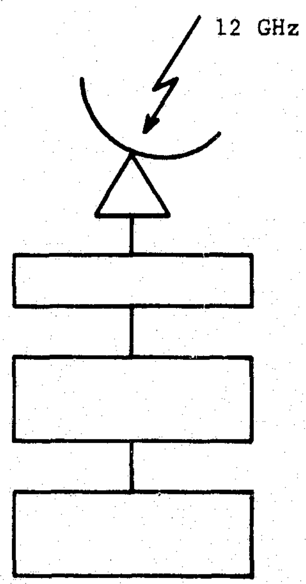
Cost of 10m/12-Band Networks Relative to That of 30m/7-Band Networks

- Readout Station Cost, x 3
  - larger antennas and better pointing
  - high-speed buffer
  - higher frequency rf equipment
- Preprocessing Cost, x 2
  - higher data rates by 15.5
  - large increase in state-of-the-art
- Archive Storage Cost, x 2
  - larger volume by 15.5
  - large increase in state-of-the-art
- Domsat ET Cost, x 4
  - larger antennas
  - multiple channels
- Leased Transponder Cost, x 8
  - 15:1 higher data rates
  - 50% reduction in space segment costs (state-of-the-art increase; supply and demand)
- Labor (Equipment Handling; Integration, Installation and Test; Profit; Operation and Administration), x 1
  - man-machine interface state-of-the-art increases

11.7 User Costs.

The network costs derived in the previous section did not include the cost of the user terminal required to receive the data from the communication satellite. To estimate an annual cost per user, it is assumed that the network costs are divided evenly among all users. While this is not likely to be the case in actual practice, the results should indicate the cost to an average user.

Each user owns a small receive-only terminal operating at 12 GHz which consists of the equipment shown in Figure 11-13 (see also Figure 7-15 and Table 7-18). This figure also shows the breakdown of equipment costs which total \$75K. This cost is used in deriving a total annual user cost where the annual cost for network 5 (from Table 11-9) is divided equally among n users. This is shown in Table 11-16. For example, for n = 100, each user pays \$30.5K per year as his share of the network costs plus \$20.5K per year for his terminal costs. Assuming a demand of 500 scenes per year for the average user, the cost per scene is \$102.



	COST - \$K
5 m DIAMETER LIMITED MOTION ANTENNA	12
LOW NOISE PREAMP (120°K)	18
DOWN CONVERTER AND DIGITAL RECEIVER (DEMOD)	20
ADDRESS AND DATA EXTRACTION	20
MISCELLANEOUS	5
TOTAL EQUIPMENT COST	75 K

Figure 11-13. User Terminal Equipment

The above analysis gives a rough idea of what an automated high-speed data-dissemination network would cost to a user. Actual user cost per scene could vary significantly from the figure derived above, depending upon the degree to which the earth-resources program is subsidized by the government, the number of users sharing the costs, and the number of scenes required. Furthermore, user processing (classification, analysis, display) costs must be added to obtain the total cost.

Table 11-16

User Costs

$$\text{AVERAGE ANNUAL COST} = \left(\frac{\text{ANNUAL NETWORK COST}}{n}\right) + \left(\begin{array}{l}\text{INITIAL INSTALLED}\\ \text{USER TERMINAL COST}\end{array}\right)^{*} \times (1/5.2)^{**} +$$

$$(2.5K + 0.10 \times \$75K)^{***}$$

$$= 3046K/n + 109K \times Q(n)^{****} \times (1/5.2) + 10K$$

$$= 3046K/n + 21K \times Q(n) + \$10K$$

=

n	25	50	100	200
AVG. AC	145K	\$83K	\$51K	\$35K

n = Number of Users
No Operator Required for User Terminal Operation
No Facility Costs

* Equipment Cost x Quantity Procurement Factor + Equipment Handling Cost (10%) + Installation, Alignment, & Test (20%) + Profit (10%)
$= EC \times Q(n) \times 1.1 \times 1.20 \times 1.1$ (Non-Tracking Antenna, Single-Rate Demodulator)

** Amortization of Capital (7 years, 8%)

*** Annual Maintenance (10% of Equipment Cost + 2.5K)

**** See Figure 7-17 for a definition of the quantity procurement factor, Q(n)

The current (1975) user cost for digital data on computer-compatible tapes (CCT's) from the EROS data center in Sioux Falls is approximately $200 per scene (one tape) [6]. Two factors should be noted in connection with this cost. First, the ratio of the volume of data in a planned 30m/7-band scene from LANDSAT-D to that of a 90m/4-band LANDSAT-A scene is approximately 15. In practical terms, this would require 15 CCT's/scene rather than 1, and perhaps entact a similar 15-fold increase in cost, if the present data density of 1600 bpi were maintained. Second, in constrast to the estimated $102-per-scene cost developed above, the dollar value of current EROS products covers the cost of reproduction only and does not include any of the following: total EROS center costs, NASA operating costs associated with data reception, costs of data transfer from reception sites to the central data center, the National Data Processing Facility (NDPF) costs, or correctional processing costs including NDPF operations. In addition, the costs of data transfer from the Sioux Falls data center to the user are not included.

11.8 Impact of Data Compression.

Data compression has the potential to decrease the costs of trunking data. The decrease was determined for network 5 -- the trunking link from Fairbanks to Sioux Falls -- for various assumed values of the cost of the data compression equipment and for pre-compression trunk-transmission rates appropriate for 30m/7-band and 10m/12-band data. The results are shown in Figure 11-14. Details of the calculations are given in Appendix I. From a previous

NASA-funded study [1], a compression ratio of 4:1 seems achievable with little or no distortion. This ratio was assumed here.

The conclusion is that data compression would have little or no effect on a 30m/7-band network but could realize significant savings in a 10m/12-band network.

11.9 Summary and Illustration.

The least-cost network either for Alaska and lower-48-state data collection and dissemination or for lower-48-state coverage only, is one using central reception (as much as possible) and preprocessing facilities. Network costs will be further minimized with broadcast user transmission. The transmission rate (Mbps) will be determined largely by the ERS-to-readout-terminal data rate but need not be more than 6 Mbps to handle both data trunking and broadcast user transmission for 30m/7-band data. The required preprocessing time per scene must

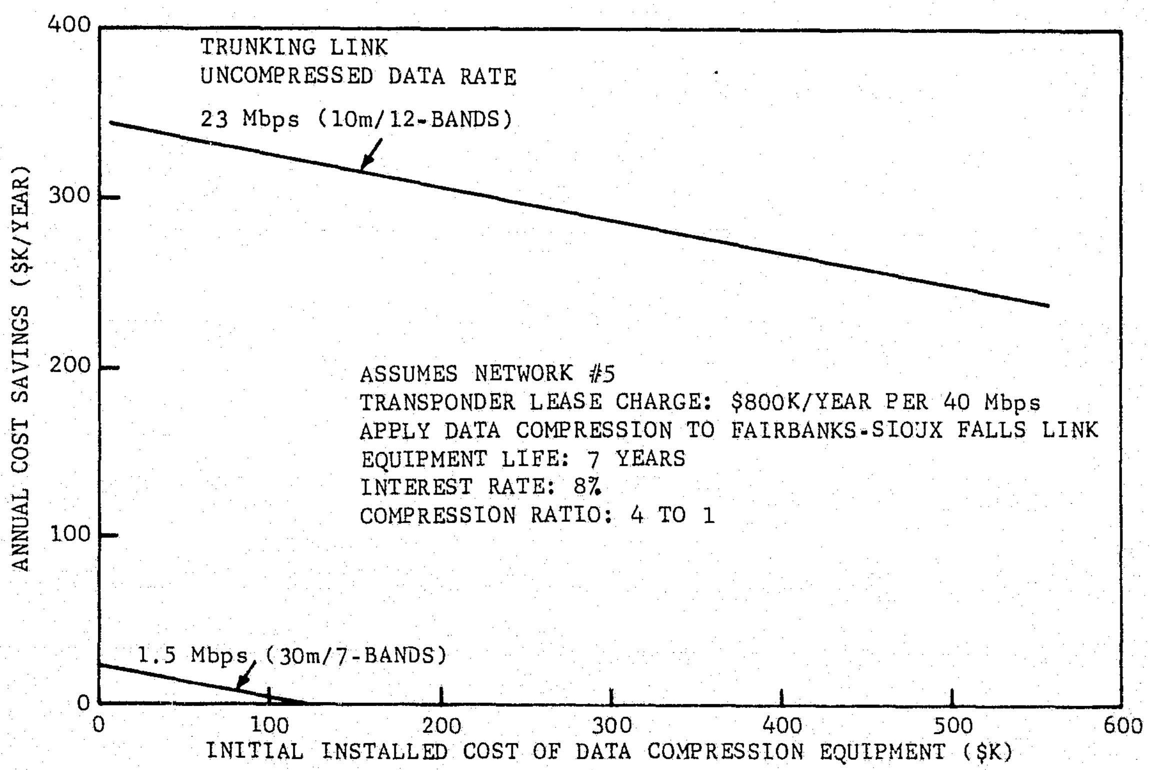


Figure 11-14. Annual Cost Savings with Data Compression vs Initial Cost of Data Compression Equipment

be geared to the input data volume with 10 min/scene being adequate for lower-48-state-plus-Alaska coverage. This translates into preprocessor speeds of approximately 70K pixels/sec and 630K pixels/sec for 30m/7-band and 10m/12-band data, respectively.

The implementation of network 5, the least-cost network covering the lower-48 states and Alaska, is illustrated in Figure 11-15 for 30m/7-band data. The ERS raw data link parameters are given in the first column of Table 7-10. The domestic communication satellite link parameters are given in Figure 11-16. As mentioned previously, the domestic satellite link utilizes a single frequency channel which is time-shared between the Fairbanks-to-Sioux Falls trunking link and the user broadcast transmission link. The trunking link has first priority. The central facility at Sioux Falls is implemented according to the block diagram shown in Figure 11-17. It is described in detail in Section 9.

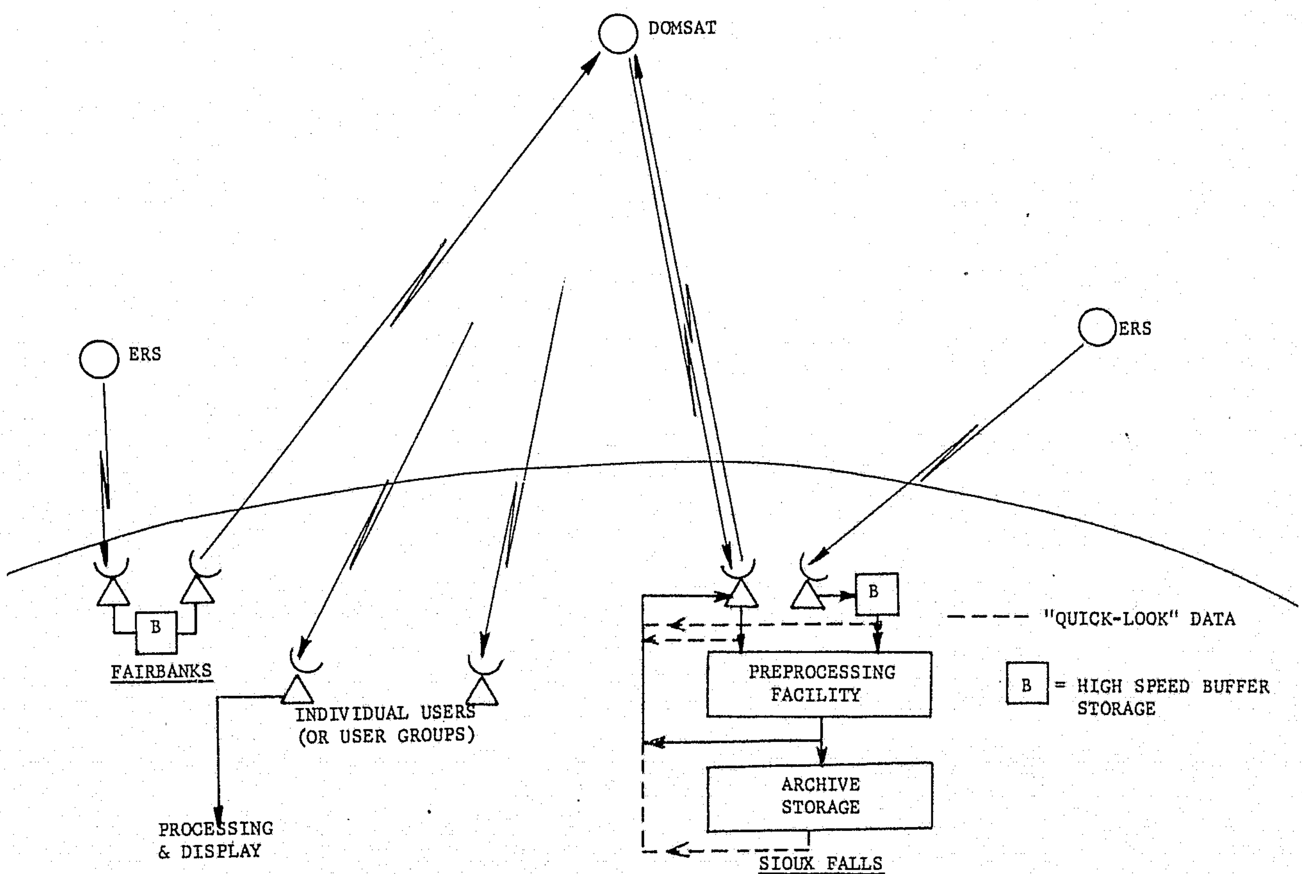


Figure 11-15. Illustration of Network 5 Implementation

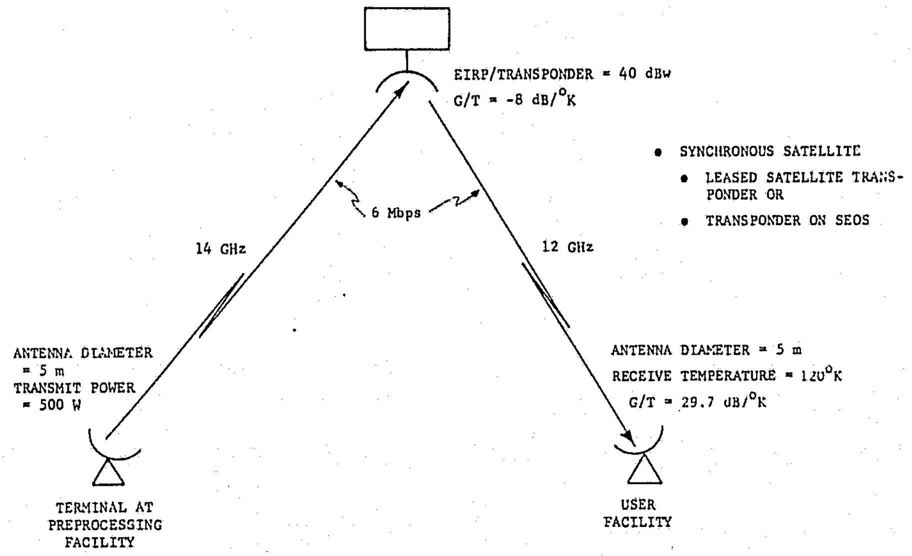


Figure 11-16. Domestic Satellite Link Parameters for Implementation of Network 5

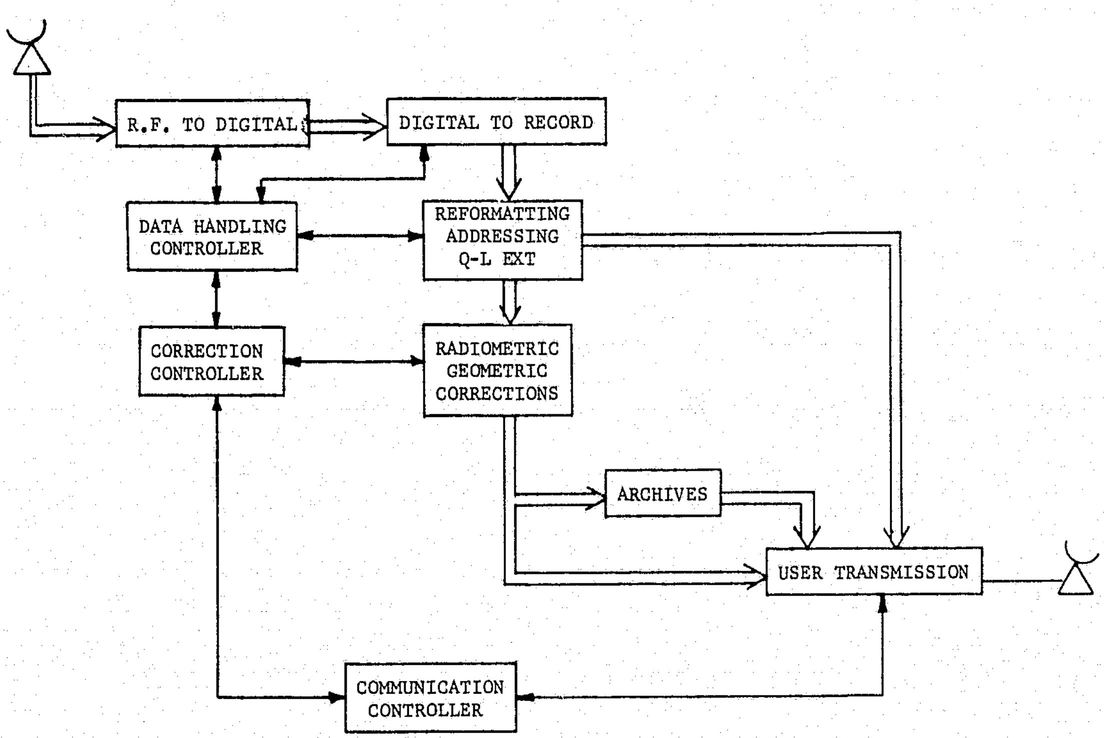


Figure 11-17. Baseline Central Facility (30m/7 Band)

SECTION 12.0
TECHNOLOGY REQUIREMENTS

Required technological development is paced by two factors, both related to speed; namely, data rate and throughput. All equipment in a dissemination network can be classified as data-rate dependent or througput dependent. This section presents required development by that classification. In addition, development, in this report is classified as non-recurring design and research, the latter reflecting necessary experimentation.

12.1 Data Rate Dependent Equipment

All equipment associated with signal reception through the first recording is data-rate dependent. Serial-to-multi-channel conversion naturally reduces this dependency. Multi-phase shift keying is a modulation technique that, in effect, performs this conversion at the data source. For example, quadrature-phase shift keying (QPSK), is currently the most efficient digital transmission scheme, time allows the use of equipment at half the data rate. For earth-resources data, another technique is serial-to-band conversion soon after conversion to the digital baseband. Thus, at least for the data rates considered in this study, there are design approaches to circumvent technological constraints.

This study focused on a data rate range from 100 Mbps to 1600 Mbps. Data rates at the lower end (100 Mbps) can be accommodated by all equipment with existing technology. The first factor to be considered, as this data rate is increased, is the allowable bandwidth allocation. At about 120 Mbps, it is necessary to increase the carrier frequency in order to remain within the allocated bandwidth. This is discussed in Section 7.1.1 of this report. Carrier assignment is dependent on the type of service. In section 7.1.1 three frequency allocations were indicated as possible for earth-resources data. These were 14.45 GHz, 20.7 GHz, and 40.5 GHz. The actual availability of and assignment to these bands is dependent on international agreement.

Technically, data rates up to 120 Mbps could be serviced at the 14.45-Ghz band. No development would be required in this frequency band for any ground-based equipment. Space-to-space links such as from a polar orbiter to a TDRS will, however, impose engineering development of a large pointable antenna.

At the 20.7-GHz band, non-recurring engineering will be required for all radio-frequency components from the preamplifier to the demodulator. However, no research development is required.

At 40.5 Ghz, where rain attenuation becomes a critical factor, emphasis must be placed on low-noise operation. This may be circumvented, in part, by location of ground terminals.

Also, further research is required to gain an accurate assessment of rainfall attenuation.

As the data rate is increased above 120 Mbps, the next critical technological constraint occurs at the recorder. At about 300 Mbps, magnetic tape recorders reach a technological limit. Above this rate, magnetic tape recorders would need to be parallel -- an approach which creates prohibitive synchronization problems for a precise serial data stream. The use of magnetic tape recorders, therefore, requires research development. This development should be directed essentially toward increasing the packing density. Current operational technology is in the vicinity of 33 kbpi (kilobits per inch). An increase in this packing density can be accomplished with digital data by coding techniques [1]. Packing densities up to 50 kbpi are now design goals. Given this accomplishment, data rates accommodated by a single recorder could be extended to about 450 Mbps.

Optical recording is an alternative technology for higher data rates. Harris Radiation, Inc. has demonstrated hologram recording on 35mm film at 600 mbps [2]. Using QPSK modulation, this data rate could be extended by a factor of 2 thus accommodating a 1.2-Gbps serial signal. Given research development, the direct-record rate could be increased to 1 Gbps which, with QPSK modulation, would accommodate the 1.6-Gbps signal associated with 10m/12-band data. However, optical recording is currently restrained by the playback speed which is about a factor of 50 less than the record speed. This is a throughput speed constraint. Research development would be required on optical playback rates.

Digital components are now operating at gigabit rates. Front-end digital circuits would require engineering development but not research at rates above about 250 Mbps. This development would not, however, be greater in cost than the normal non-recurring cost for any special digital design. Again, QPSK modulation would allow data handling up to the 1.6-Gbps data rate.

In summary, required research development is dependent on the frequency allocation. At 40 GHz, rain attenuation effects and design approaches must be evaluated. Above 300 Mbps, further research is required on magnetic tape recording. Above 600 Mbps, further research is required on optical recording. If the latter is employed, research is required on playback techniques to satisfy throughput rates.

12.2 Throughput-Dependent Equipment.

If band-parallel processing is used, no research technology development is required on digital components. As suggested in section 9.0, all digital operations can be performed on-the-fly. Non-recurring engineering will be necessary for any special device.

The major bottleneck is in the area of geometric correction. Current technology using limited distributed processing will accommodate throughput rates for current correction schemes at about 3.75 microseconds per pixel. Increasing this rate is heavily dependent on specific system design. In addition to higher computational speeds that can be expected with array processors, major gains can be expected through changes in computer architecture. Technological development now in process should extend the throughput speed to 1 microsecond per pixel [3]. Depending on the required scene production rate, spatial resolution in excess of 30m will require further research development. Quite likely this development will be the result of current trends independent of earth-resources data requirements.

For example, the introduction of the large scale integrated (LSI) circuit is creating a major change in computer architecture. The emphasis on maximizing the utilization of an expensive resource, the central processing unit, is no longer the primary concern. Computers may now be configured in a functional manner to accomplish a specific task in an economical manner as a result of the mini/micro-computers, which are a consequence of the large number of circuit components on a single chip. The maximum components/chip as a function of time since 1960 is shown in Figure 12-1.

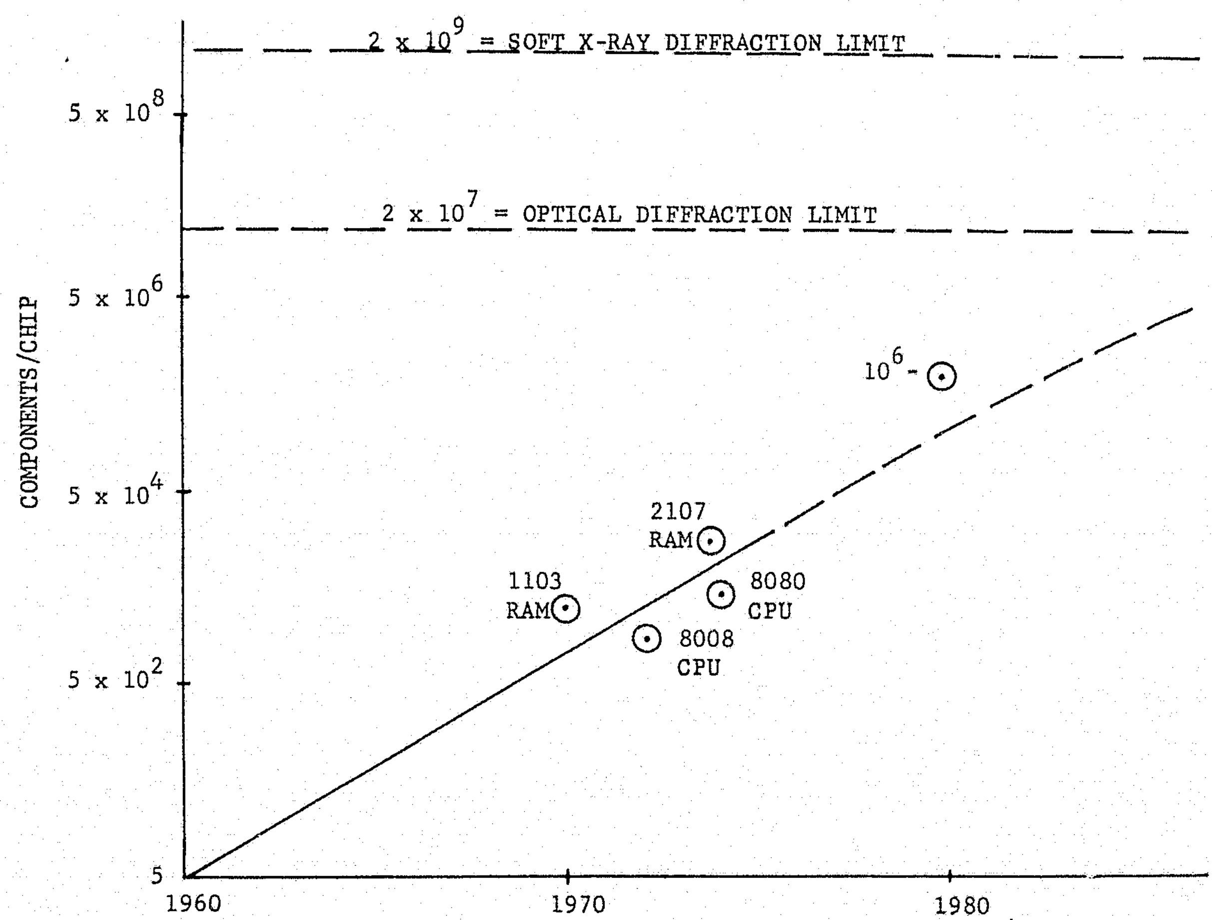


Figure 12-1 Maximum Components/Chip vs Time (Projection)

The limitations posed by optical diffraction are being bypassed with the introduction of electron beam and soft x-ray lithography [2]. Typical improvements to be expected by use of the advanced lithography is a reduction from 5-μm lines to 1-μm lines with a 25:1 increase in density and a 125:1 improvement in the power-delay product. Circuit speeds should improve by a factor of 5.

If increased resolution implies proportionally increased registration accuracy of a fractional pixel, then another constraint will be introduced in error models of 3-axis stabilized platforms. The outputs of such models are employed to narrow the window of extracted GCP's in the primary data stream. Thus, the time for GCP matching to reference GCP's is dependent on the error model accuracy. Research development will be required in software at 30m or greater resolution if fractional pixel registration accuracy is required. It should be noted that there are now no positive results relating classification accuracy to registration accuracy. Thus, such technological development may not be necessary.

Figure 12-2 summarizes required technological development. The horizontal axis indicates data rate, spatial resolution, and preprocessing time per pixel to achieve a 10-minute-per-scene production rate. The spatial resolution was normalized on 7 spectral bands.

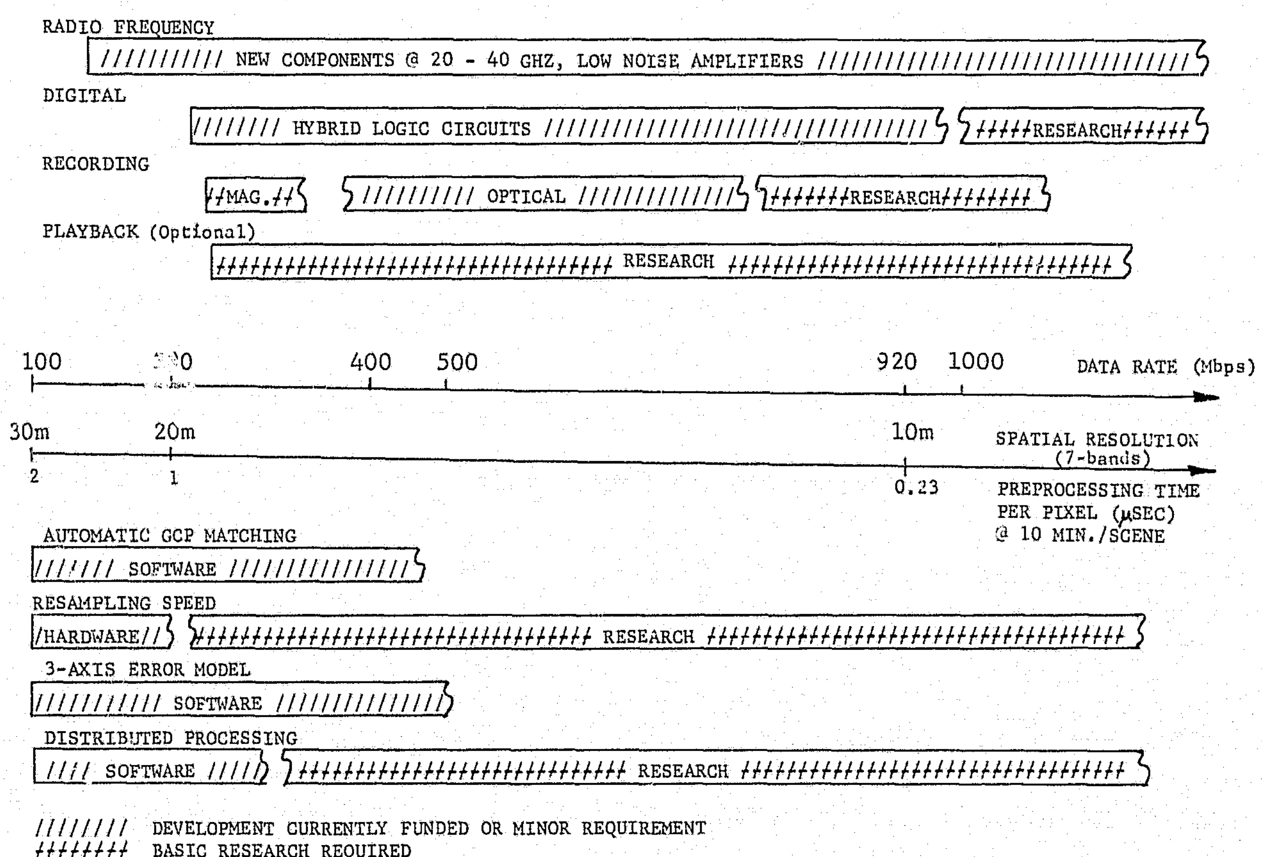


Figure 12-2. Technology Requirements

SECTION 13.0

CONCLUSIONS AND REDOMMENDATIONS

13.1 Conclusions.

The major conclusions from this study are as follows:

a. Data from satellites in sun-synchronous polar orbits (700-920 km) will generate most of the earth-resources data in the 1985-1995 time period.

b. Data from aircraft and shuttle sorties, being either on film or tape, requires specialized processing and handling, and cannot be readily integrated in a data-dissemination network unless already preprocessed in a digitized form to standard geometric coordinate system.

c. A potential demand now exists for earth-resources data delivered within 1-2 days after reception by a data readout station. The U.S. Department of Agriculture and the U.S. Department of Interior are major potential users of such data.

d. Data transmissions between readout stations and central preprocessing facilities, and between preprocessing facilities and user facilities are most economically performed by domestic communication satellites. This is especially true for a 10m/12-band system. The satellite transponder channel is either leased, or a transponder may be placed on a geosynchronous earth-resources satellite. User earth terminals for data reception may be leased or owned by the user. An exception to the above is when a user requires a small amount of data (less than 1 scene of the 30m/7-band data)* and the distance is less than about 600 miles, in which case, common-carrier terrestrial links are more economical if timeliness is not critical.

e. Transmission of preprocessed data to the user by satellite is most economically accomplished by broadcasting all the data, scene-by-scene, suitably identified by address codes so that each user can automatically extract the data of interest.

f. Given that most users will receive their data via broadcast satellite, a single facility consisting of a centrally located readout station, preprocessing equipment and data dissemination equipment is more economical that networks with distributed or separated facilities. This is true over a wide range of costs for the preprocessing equipment.

g. All data can be preprocessed and broadcast to the user within one day of reception from the earth-resources satellite provided a preprocessing time of 10 to 15 minutes per scene is achieved and is coupled with a communication satellite link capacity of 6 Mbps for the 30m/7-band case, and 120 Mbps for the 10m/12-band case.

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* 1 scene (all bands) of 30m/7-band data is less than 1/15th scene (all bands) of 10m/12-band data.

h. Real-time user interaction with the data dissemination newtork is feasible provided the interaction is based on quick-look data; i.e., unpreprocessed data. In light of conclusion (g), a substantial volume of data from quick-look requests is not foreseen. Furthermore, the impact of user interaction on the total system cost is small.

i. Use of TDRS is not cost effective for continental USA coverage, unless the cost of TDRS is less than $100K/year. However, if the data-dissemination network is expanded to cover areas outside of the North American continent, then TDRS probably becomes more economical than the implementation and operation of additional readout stations. TDRS has insufficient capacity for the 10m/12-band system.

j. The addition of Alaska (including its continental shelf) to the lower-48 states increases the total data volume by 50% and the annual cost of implementing and operating the data dissemination network by approximately 3[illegible]

k. The implementation of a LANDSAT-D type system (30/meter resolution with 7 spectral bands) is technically feasible and within today's state-of-the-art.

l. The implementation of a 10-meter resolution system with 12 spectral bands requires a considerable advance in the state-of-art, especially in the development of high-frequency (20-40 GHz) high-data-rate (1.58 Gbps) technology, and accurate (10 meter) high-speed (0.15 s per pixel, or 10 minutes per scene) geometric correction technology.

m. From an overall cost standpoint, the use of data compression equipment in disseminating 30m/7-band data does not seem justified. Use of data compression may be justified in a 10m/12-band system.

n. A direct readout link for a 30m/7-band system will require a 100-MHz channel bandwidth allocation. A carrier frequency of 14.45 GHz is recommended. For a 10m/12-band system, a channel allocation of at least 1 GHz is required. The 20.2-21.2-GHz band is recommended. An alternative is the 40-41-GHz band.

13.2 Recommendations.

With the methodology and computer simulation program developed under this contract, a number of additional studies could be performed:

a. Examine effect of cloud cover on system performance, required parameters, and cost. A statistical model would be developed which would be incorporated in the simulation program.

b. Examine impact of expanded coverage, including Hawaii, and international areas.

c. Define and simulate the function of the area center. Expand to include user-unique processing and user interaction.

d. Optimize the network parameters for other user demand models.

e. Examine impact on user costs of various strategies for allocating network operation costs (e.g., pricing strategies).

The use of earth-resources data is still in its early stages of development. It is expected that both user requirements and applicable technology state-of-the-art will change significantly over the next few years. Such changes should be taken into consideration when interpreting the results of this study in the future.

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